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DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
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BRIQUETTING TESTS OF LIGNITE

AT PITTSBURG, PA., 1908-9

WITH A CHAPTER ON SULPHITE-PITCH BINDER

BY

CHARLES L. WRIGHT

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BRIQUETTING TESTS OF LIGNITE AT PITTSBURG, PA. JULY 1, 1908, TO JUNE 30, 1909.

By CHARLES L. WRIGHT.

INTRODUCTION.

PROPERTIES OF LIGNITE.

Coals may be divided into six classes—anthracite, semianthracite, semibituminous, bituminous, subbituminous, and lignite. The first three classes can be distinguished by differences of composition, particularly the proportions of fixed carbon and the ratios of the fixed carbon to the volatile matter in the coals. The last three classes can be distinguished by differences in physical character, chiefly in color and in manner of weathering.

Lignite is brown, not black, and has generally a woody look, but it weathers in much the same way as subbituminous coals. On exposure to the air lignite slacks or crumbles. The lumps check and fall into small irregular pieces that exhibit a decided tendency to separate into extremely thin plates. Hence lignite deteriorates greatly during storage or long transportation.

The most characteristic feature of the composition of lignite is a large percentage of moisture. This high moisture content reduces the fuel value of freshly mined lignite, and the partial evaporation of moisture, on exposure, causes the fuel to check and fall to pieces. Consequently, attempts to increase the efficiency of lignite as a fuel involve reducing its percentage of moisture and increasing its ability to endure storage and transportation. Both these results are accomplished by briquetting.

LIGNITE FIELDS IN THE UNITED STATES.

The total extent of territory in the United States that may contain workable beds of lignite is much greater than the extent of the deposits known to be workable. The United States Geological Survey estimates the area underlain by possibly workable beds to be 148,609 square miles. Millions of acres of this land belong to the Government.

The principal workable deposits of lignite are within the northern Great Plains province, which occupies most of the western half of

North Dakota, part of the northwest portion of South Dakota and much of the eastern half of Montana. In this province many thousand square miles of land are underlain by workable beds, the workable beds in North Dakota alone, according to the United States Geological Survey, underlying 31,240 square miles. Deposits of lignite extend completely across the State of Texas, but the deposits regarded as workable are in scattered districts that have a total area of about 2,000 square miles. Workable lignite deposits occur in several other States.

UTILIZATION OF LOW-GRADE FUELS IN EUROPE.

For many years European countries have been developing supplies of fuels that have low heat values, and have succeeded in making the utilization of peat, lignite, and the screenings of bituminous coal and anthracite the basis of important industries. In several countries large amounts of capital have been invested in the manufacture of fuel briquets. The magnitude of the briquet industry in Germany and the part it plays in utilizing the lignite or brown-coal deposits of that country are shown by the fact that in 1910 the German Empire produced 19,561,494 metric tons (21,575,000 short tons) of briquets, of which 15,120,255 metric tons (16,675,000 short tons), or 77 per cent of the total output, were made from lignite. These lignite briquets are much liked for domestic use, and form the chief household fuel in many large cities.

TESTS OF LIGNITE BY THE UNITED STATES GOVERNMENT.

The United States Geological Survey in connection with the work of the coal-testing plant erected at St. Louis, Mo., in 1904, undertook an investigation of the merits of lignite as a fuel, with the object of ascertaining the most efficient methods of utilizing it. The survey made briquetting tests of lignite and also combustion tests of lignite briquets and of raw lignite in boiler furnaces and in gas producers at St. Louis, Mo., and at Pittsburg, Pa. The results of the tests of lignite at St. Louis are to be found in United States Geological Survey Bulletins Nos. 261, 290, 332, 343, and 363, and Professional Paper 48. (See Bibliography.)

In the spring of 1907 the steam-engineering, gas-producer, and briquetting sections of the fuel-testing plant were removed from St. Louis, Mo., to Norfolk, Va., where the Jamestown Exposition Company provided a building for their use. The briquetting tests at Norfolk were confined to coals from Virginia and West Virginia.

During the fall and winter of 1908 most of the fuel-testing equipment used at Norfolk was removed to Pittsburg, Pa., and erected there. Various improvements were made, and early in 1909 the briquetting plant was in operating condition.

The briquetting tests described in this bulletin were of lignites from North Dakota, Texas, and California. Steaming tests of North Dakota lignite were made at the Reclamation Service pumping plant at Williston, N. Dak., under the direction of D. T. Randall and Henry Kreisinger, and have been described in Bureau of Mines Bulletin 2. Combustion tests of raw lignite in house stoves of special design have also been made.

The act establishing the Bureau of Mines authorized the transfer of fuel-testing investigations from the Geological Survey to the new bureau. This act became effective July 1, 1910, and in consequence of the transfer of the investigations this bulletin is published by the Bureau of Mines, though it deals with work done by the technologic branch of the Geological Survey in the fiscal year ended June 30, 1909. The funds available for fuel investigations by the Bureau of Mines are not sufficient to enable the bureau to carry on the lignite-briquetting investigations on a practical scale.

PURPOSE OF BRIQUETTING TESTS.

Briquetting tests of lignite were undertaken at the fuel-testing plant at Pittsburg to ascertain the following facts:

1. The possibility of briquetting American lignites without adding binder to them.

2. The suitability of the German brown-coal briquet presses for briquetting American lignites.

3. The percentage of moisture needed in the briquet material to give the best briquets.

4. The approximate commercial cost of briquetting lignites.

5. The weathering qualities of briquets as compared with raw lignites.

An additional purpose of the tests was to provide a supply of lignite briquets from which to determine their value as (a) steaming fuel under boilers, (b) gas-producer fuel, and (c) domestic fuel.

RESULTS OF BRIQUETTING TESTS.

The results of the briquetting investigations conducted by the Government are expected to prove of considerable value, not only to the Government itself as the owner of extensive lignite deposits and the largest single purchaser of fuel, but also to the people living in the regions where lignite is found. The problem of a fuel supply in those regions is of peculiar interest, for many of the lignite deposits are situated long distances from fields of high-grade coal. The problem assumes still larger proportions when one realizes that the development of manufacturing industries in those regions depends upon the ability to obtain a cheap and satisfactory fuel.

Although the results presented in this bulletin are not conclusive, they warrant the continuation of the investigations as soon as funds can be made available for the purpose. Enough testing has been done to indicate that some American lignites equal German lignites in fuel value and can probably be made into briquets on a commercial scale without the use of binding materials. Three samples of lignite, one from Texas, one from North Dakota, and one from California, were made into satisfactory briquets without the addition of a binder. It was proved that some lignites after having slacked by exposure can be made into briquets without the use of binding material, notwithstanding a general opinion that this could not be done. Cohesion and weathering tests demonstrated that good briquets endure handling and resist weathering much better than the lignite from which they are made.

PERSONNEL.

A. W. Belden had general supervision of the work of the coking, washing, and briquetting sections of the testing plant at Pittsburg. Charles L. Wright designed the briquetting plant and was responsible for its erection; he also had charge of the briquetting and other tests of the raw fuel and the various physical tests of the briquets. H. L. Gardner rendered valuable aid in recording observations and assisted in making the physical tests. Otto Lehman, a machinist in the employ of the manufacturers of the German lignite press, was engaged from November, 1908, to April, 1909, to superintend the erection of the press and to assist in its operation. The writer takes this opportunity to acknowledge the faithful and efficient work of the pressmen and laborers engaged on the briquetting tests.

BRIQUETTING PLANT AT PITTSBURG.

GENERAL DESCRIPTION.

At the experiment station of the Bureau of Mines, at Pittsburg, a complete lignite-briquetting plant is installed in the main part of the briquetting building. This plant was built by the Maschinenfabrik Buckau Actien Gesellschaft zu Magdeburg, Germany. As received from the maker, the plant included the following equipment: A tubular drier, a sorting sieve, auxiliary crushing rolls, a cooler, a screw conveyer, a large storage hopper, a briquetting press directly connected to a steam engine, apparatus for conveying the briquets, shafting, hangers, and extra sets of dies. To complete the plant, the Survey erected a coal elevator, a crushing roll, and the necessary belting and piping, in addition to the building and stacks.

The English machine used at St. Louis and Norfolk for briquetting anthracite and bituminous slack and coke breeze was set up in the

BRIQUETTING-PLANT BUILDING.

building, but no provision was made for using it to briquet large quantities of fuels during the period covered by this report. Instead, work was concentrated on tests of lignite with the German machine.

BUILDING.

The briquetting machines and their equipment are housed in a steel-framed building inclosed with curtain walls of reinforced concrete 2 inches thick. The steel work is of heavy construction, for it has to carry not only the machinery, but also, on the third floor, a storage room to hold 100 tons of coal or lignite. Plate I illustrates the general apearance of the building.

FIGURE 1.—Longitudinal section of lignite-briquetting plant.

EQUIPMENT AND OPERATION OF PLANT.

CONVEYER AND CRUSHER.

Two bins of 60 tons capacity each for storing the raw lignite were built near the car track at one side of the briquetting building, so that the lignite could be shoveled directly into them from the box cars in which it had been shipped from the mine.

A bucket elevator (figs. 2, 3) of the link-belt type was erected to carry the raw lignite from the ground to the third floor of the building.

The single-roll crusher A (figs. 1, 2) was installed in the bin room on the third floor. The roll had a corrugated surface and the material passed between it and a dead plate. The crusher and the raw-material elevator were driven by a motor through line shaft R, as shown in figure 2.

FIGURE 2.—Cross section of lignite-briquetting plant.

The crusher was expected to break run-of-mine lignite down to pieces ⅜ inch in diameter or smaller, but it would not do so at one pass. Some samples of lignite had to be run through the crusher several times after the larger pieces had been broken with a hammer. The North Dakota lignite acted like tough wood and was especially hard to crush.

The experience gained from the tests indicates that lignite should be crushed in stages; first by a toothed roll and then by a smooth or corrugated roll or by a disintegrator. In Germany three sets of crushers are used in lignite-briquetting plants.

A. RECEIVING END OF SCHULZ DRIER.

B DELIVERY END OF SCHULZ DRIER

DRIER.

The Schulz tubular drier C (figs. 1, 2) was installed on the second floor of the building. It was similar in shape to an ordinary multi-tubular boiler, 22½ feet long, 7½ feet in diameter, and had 195 tubes of 3¾ inches inside diameter, evenly spaced around the drum. The material to be dried passed through the tubes, which had a drying surface of 4,310 square feet.

This drier, which weighed 27 tons, was supported at the ends, the receiving end (Pl. II *A*) being about 3 feet higher than the delivery end (Pl. II *B*). A step bearing at the lower end took the end thrust. A worm gear turned the drier at a speed of 5.2 revolutions per minute; the material to be dried passed through the tubes by gravity.
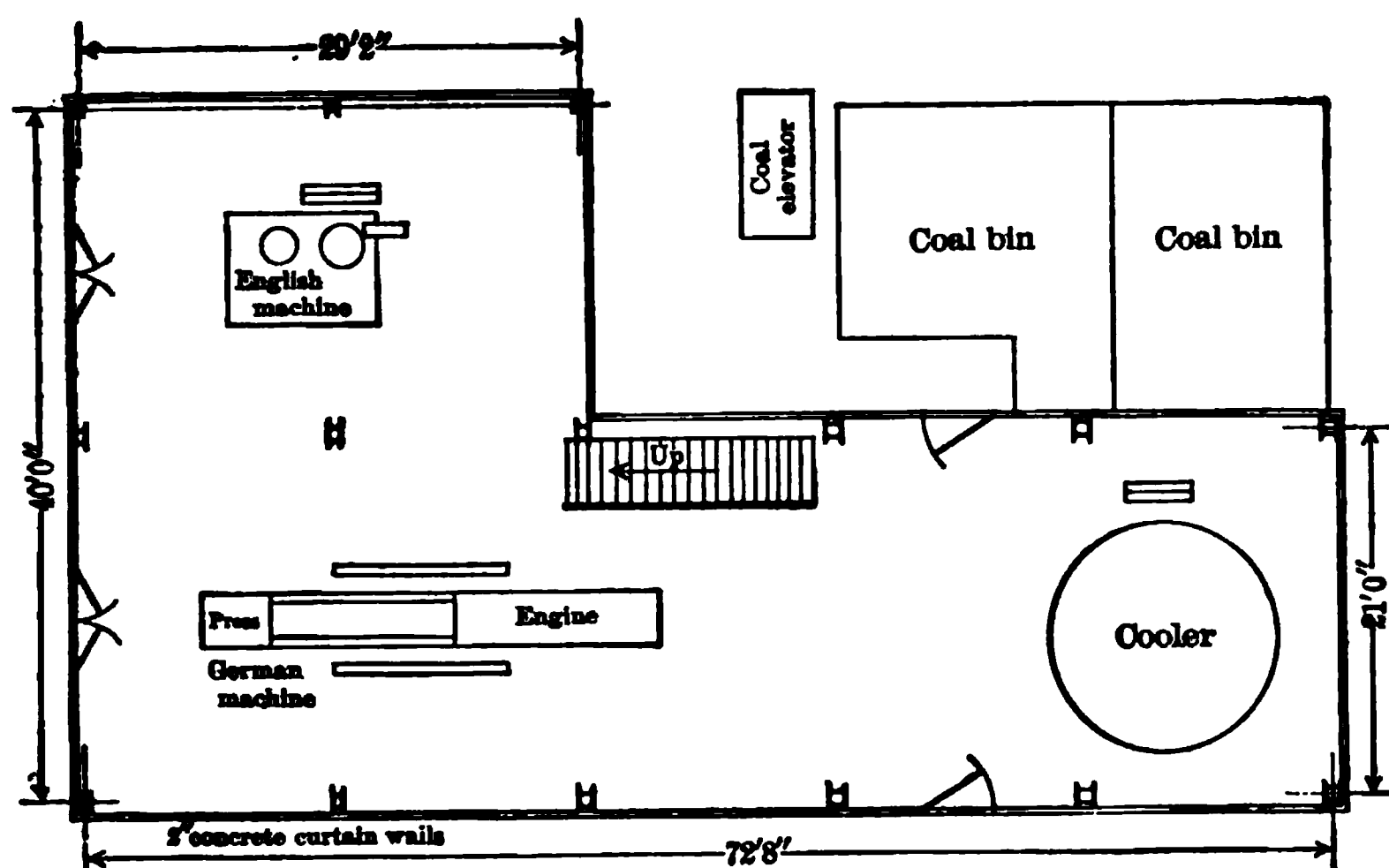
FIGURE 3.—Plan of first floor of briquetting plant.

A 5-inch pipe carried the exhaust steam from the engine of the briquet machine to the drier, the steam entering the latter through the upper bearing. A safety valve on the pipe could be set to keep any desired pressure on the drier. During the tests steam pressures of 3 to 30 pounds per square inch were used, according to the degree of dryness desired. A 2-inch pipe fed live steam into the drier when the engine was not running. The ground lignite was fed into the drier tubes by a chute (shown in Pl. II *A*) that led from an opening in the third floor, under the roll crusher.

The lower or delivery end of the drier was connected with a revolving screen by a hopper (D, figs. 1, 2 and Pl. III *A*). This screen had openings of two sizes; those in the receiving half were $\frac{7}{16}$ inch square, and those in the other half were $\frac{5}{8}$ inch square. Material

larger than ⅜ inch was discharged from the end of the screen through a waste pipe.

The sheet-metal casing under the screen had two legs. The material that passed the 1/16-inch openings fell through one leg, F', (fig. 2) into the cooler, while the material passing the ⅜-inch section of the screen fell on a pair of rolls, was crushed to a fine powder, and then fell into the cooler through the other leg, F.

<div align="center">COOLER.</div>

The cooler (G, figs. 1, 2, and Pl. III A) was of the plate type. It had four circular stationary plates 13 feet in diameter, arranged one above the other, with raised edges and closing plates to keep the dust from escaping. Over each plate four radial arms, each carrying several scrapers set at an angle of 45° with the arms, were revolved by a vertical central shaft. The material was scraped from the outer edge of the highest plate toward the center, where it fell through holes to the plate below; another set of scrapers moved it to the outer edge of that plate and another set of holes. Thus it reached the bottom plate, from which it went to a worm conveyer (H, fig. 1 and Pl. III A). This conveyer elevated the cooled material to the second floor where it fell, through chute I, into large hopper K over the German press L (fig. 1).

The drier C, sorting sieve E, crushing rolls F, cooler G, and worm conveyer H were driven from the main shaft S, which in turn was driven by the 50-horsepower motor N.

<div align="center">DUST STACKS.</div>

The dust and gases from drying lignite may form explosive mixtures with air; hence stacks W and X (fig. 1) were erected over the delivery end of the drier to carry off the dust and gases, as shown by the arrows in figure 1, and to keep them from coming back into the room through the ends of the tubes near B. An explosion door was placed at the upper end of stack W. Most of the dust settled in the down-coming section of stack W and went to hopper D through a chute. A spray was put in stack X to wash out any dust that remained in the gases, and to condense steam and other vapors. The air current up the stacks tended to increase the capacity of the drier.

<div align="center">GERMAN MACHINE.</div>

The German machine (Pl. IV) was designed to briquet either peat or lignite that will cohere under pressure because of inherent bituminous matter. The press was not intended for briquetting ma-

terials to which a binder has been added, and attempts to use a similar press for briquetting materials containing artificial binder will probably result in a stalled machine or a broken stamp.

The machine is of the open-mold type, and the material pressed passes through the mold. In its passage the material is reduced in volume, because the opening in the delivery end of the mold is smaller than the one in the receiving end. This difference in size of the two openings is shown by the vertical sections through the mold given in figure 4, the vertical height being greater at *a* than at *b*. The dimensions given in the figures are in millimeters.

A charge of the prepared material sufficient for one briquet enters the mold at C, is pressed by the stamp E into the end of the mold and is pushed along to D, the end of the travel of the stamp E. The stamp moves back, and then presses another charge to D. The first charge is forced along under heavy pressure in the direction of the

FIGURE 4.—Vertical sections through mold box of lignite-briquetting press; dimensions are in millimeters.

arrow until it reaches *a*; as it passes from *a* to *b*, in what is called the die angle, it is compressed at top and bottom by the reduction in height of the mold. From *b* the briquet is forced along by the successive charges of material and its sides are hardened and polished. When it leaves the mold at F, the briquet is hot, but after it has traveled in a trough for a few feet from the machine it is ready for storage or loading into cars. The press L (fig. 1) is directly connected to the steam engine M. The stamp E (fig. 4) is bolted to a sliding headblock that is actuated by a connecting rod and eccentric. The throw of the eccentric is 7 inches.

ENGLISH MACHINE.

The English machine,[a] shown in Plate V, consists of a heating and mixing chamber of cylindrical shape; a die-filling box, also of cylindrical shape; a die-filling plunger; a vertical die plate; and double-

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[a] For a detailed description of the English machine, see U. S. Geol. Survey Bull. 385, pp. 12-14.

compression plungers. This machine is suited for briquetting any solid fuel with added binder. It was built by William Johnson & Sons, of Leeds, England.

No provision was made for experiments with this machine during the fiscal year ending June 30, 1909, and its equipment was not completed. However, a short conveyer was put in to connect the machine with a chute shown at T (fig. 1) on the worm conveyer H, so that material could be crushed and mixed with the binder on the third floor of the building and transported to the machine by the hopper D, cooler G, and conveyer H. This arrangement was not intended for making large lots of briquets, but only for short runs to determine the briquetting qualities of a sample of fuel.

COMPARISON OF GERMAN AND ENGLISH MACHINES.

The capacity of the German and of the English machine, the horsepower required to drive each, and other details are summarized in the following table:

Details of briquetting machines.

Machines.	Horse-power required.	Working strokes per minute.	Briquets per minute.	Average weight of 1 briquet.	Capacity.		Average pressure per square inch used on briquet.
					Per hour	Per 8-hour day.	
				Pounds.	*Tons.*	*Tons.*	*Pounds.*
English.........................	25	17	34	3.75	3.8	30	2,500
German.........................	100	100	100	1.00	3.0	24	20,000

The briquets made by the German press have flat sides and rounded ends. A good idea of their appearance may be obtained by referring to Plates VI to XI. They measure approximately 6¼ by 2½ by 1 inch, and weigh about 1 pound apiece. The briquets produced by the English machine are parallelopipeds, with the edges rounded off. Their average weight is 3.75 pounds.

LABORATORY HAND PRESS.

A laboratory hydraulic press (Pl. III, *B*), operated by hand, was used for preliminary investigations. It contained a mold 3 inches in diameter and 9 inches long, around which was a steam jacket. This press was adapted for tests with or without binding material and with hot or cold dies. The pressure obtainable with the 3-inch mold was 50 tons, or 14,000 pounds per square inch. By using a smaller mold that was made, a pressure of 30,000 pounds per square inch could be obtained. The press proved very useful and many tests were made with it, but since these tests were preliminary, they are not included in this report.

GERMAN BRIQUET MACHINE, ENGLISH MACHINE IN BACKGROUND

COST OF A BRIQUETTING PLANT.

It is estimated that a plant capable of producing 25 tons of lignite briquets per 10-hour day can be erected for $56,000. This estimate is based on the cost of the plant at Pittsburg, Pa., as shown below:

Cost of German lignite-briquetting plant.

German lignite-briquetting press with engine complete, with Schulz drier, cooler, worm conveyer, shafting, hangers, pulleys, etc., f. o. b. Hamburg	$16,000
Freight on outfit, Hamburg to mine in United States, 100 tons	4,000
Duty, at 45 per cent ad valorem	7,200
Building complete with foundation	15,000
Crushing machinery and necessary elevators	2,500
One 30-horsepower motor to drive crushers and elevators, with rheostat	800
One 50-horsepower motor to drive drier, cooler, etc., with rheostat	1,000
Erection of machinery	3,000
Two 100-horsepower boilers, with equipment	2,500
Surface grinder to dress dies, etc	1,000
Superintendence, miscellaneous supplies, freight, etc	3,000
	56,000

Nystrom[a] estimates the cost of a complete plant of about the same capacity to be $54,000 to $60,000, so that his figures agree with the cost of the plant at Pittsburg, including the cost of necessary changes in the crushing equipment of the latter.

The following table shows in detail the cost of a briquetting plant equipped with an English (Johnson) machine having a capacity of 38 tons per 10-hour day:

Cost of English briquetting plant.

Johnson briquetting machine complete, with heater and press	[b] $4,500
Freight, England to mine in United States, 20 tons	1,200
Duty, at 45 per cent ad valorem	2,025
Building	10,000
Crushing machinery and necessary elevators	2,500
One 50-horsepower engine	500
Boiler, piping, etc	2,000
Erection of machinery	2,000
Superintendence, miscellaneous supplies, freight, etc	3,000
	18,325

[a] Nystrom, E., Peat and lignite; manufacture and use in Europe. Canada Dept. of Mines, Ottawa, 1908, pp. 130–170.
[b] Consular Reports, No. 26, p. 100.

BRIQUETTING TESTS.

LIGNITES TESTED.

Briquetting tests were made on the following samples, which were considered typical of the lignites in the more important fields in the United States:

Samples of lignite tested.

Field designation.	Source.	Size.	Number of tests.
Pittsburg: No. 7	Rockdale, Milam County, Tex	⅜-inch lump	(a)
No. 8	Lytle, Medina County, Tex	⅜-inch lump	b 3
No. 9	Calvert, Robertson County, Tex	⅜-inch lump	5
No. 11	Scranton, Bowman County, N. Dak	Run of mine	5
No. 13	Lehigh mine, Stark County, N. Dak	....do	11
No. 14	Ione, Amador County, Cal	....do	8
No. 15	Vanderwalker, Ward County, N. Dak	3-inch lump	4

a No official tests made on this sample, which was used in adjusting the machine.
b Several preliminary tests also made.

METHOD OF MAKING TESTS.

The samples of lignite to be tested were either kept in one of the two storage bins previously mentioned or were piled upon the ground near by. All the samples were shipped to the plant in box cars.

In making a briquetting test about 3 tons of lignite were taken by elevator P (fig. 2) to the third floor and dumped there in a pile. The lignite was then shoveled into crusher A (figs. 1, 2), which reduced it to ⅜-inch or smaller pieces. The crushed material passed through a hole in the floor and chute B (figs. 1, 2) into the tubes of a drier (C, figs. 1, 2, and Pl. II A, B). The dried lignite fell into hopper D (figs. 1, 2), and the part that was fine enough to pass the $\frac{1}{16}$-inch sieve fell directly into the cooler G (figs. 1, 2) through leg F (fig. 2). The pieces larger than $\frac{1}{16}$ inch and smaller than ⅜ inch fell on a pair of crushing rolls at F (fig. 2), and when crushed dropped into the cooler (G, figs. 1, 2, and Pl. III A). All material that passed through the cooler was elevated by a screw conveyer (H, fig. 1 and Pl. III A) to the second floor and dropped through chute I (fig. 1) into a hopper (K, fig. 1 and Pl. IV). Overflow chute J (fig. 1) was intended to prevent damage to the screw conveyer H, in case the hopper K became full, by permitting the excess material to pass to the second floor through chute J. From hopper K (fig. 1) the material was fed at a uniform rate to the press L. The briquets were cooled by lying for several minutes in a trough or "slideway," shown at the front of the machine in Plate IV, from which they were carried in barrows to storage piles under cover.

SIDE VIEW OF ENGLISH MACHINE.

At each test the raw material, as it was fed into the drier, was sampled for chemical analysis and determination of heat value. The dried and cooled material was sampled as it fell into the hopper K (fig. 1), and its temperature and moisture content were determined. A sample of the briquets was taken for analysis and determination of heat value.

CHARACTER OF TESTS.

The tests described in this bulletin, as has been stated, were made on the German machine without the use of any artificial binder, the natural inherent bitumen of the lignites themselves yielding the binding material. Therefore those lignites that were not made into good briquets in the German press may be made into excellent briquets in a machine adapted to working with an artificial binder. Certainly there is opportunity for further experiments in this direction, and it is hoped that the Bureau of Mines may be able to conduct briquetting tests of lignites and different binders with the English machine.

Only small lots of lignite could be tested at a time, since the size of the large hopper over the press controlled the quantity of material dried. Until the press started, one was never sure that the material would not stall the machine. Therefore only enough material was fed to the drier to fill the large hopper, so that should difficulty be experienced in getting the material through the press, there would not be an excess to overflow on the floor. The necessity of drying small lots was unfortunate, as about 6 tons of material could be put through in the time needed to get the apparatus warmed to working temperature, and the use of only about 3 tons of lignite for a test resulted in the first part of each lot being dried more than the last part.

DIE ANGLES USED.

The " die angle," or " angle of dies," is the angle to which one end of the long die blocks is ground to decrease the sectional area of the mold, and thus compress the material passing through. The situation of this angle may be seen by referring to figure 4, in which the die angle extends from a to b; the size of the angle may be found with sufficient accuracy by dividing the decrease in vertical height of the mold (a minus b) by the length of the part ground off, and finding from a table of natural tangents the angle having a tangent equal to this quotient. To define it in another way, the die angle is

$$\text{the angle whose tangent} = \frac{\text{Decrease in vertical height}}{\text{Length ground away}}.$$

As the angular measure in degrees does not convey such exact information as do the dimensions of the portion removed by grinding, the latter are styled the " die angle " in the notes on the tests.

In figure 4 the normal or standard die angle is shown, and its size is here reported as $\frac{6}{80}$, for the decrease in vertical height in this instance is $66-60=6$ mm., and the length ground off is 80 mm. The angle whose tangent is $\frac{6}{80}$ is $4°\ 20'$. In the tests here reported various die angles were used, ranging from $\frac{1}{60}$ to $\frac{8}{68}$.

The height and length of the metal ground off the sets of dies used, the ratios of these dimensions, and the angles corresponding to these ratios are shown in the following table:

Die angles used.

Decrease in vertical height.	Length of die angle.	Ratio or tangent.	Angle of which ratio is tangent.		Decrease in vertical height.	Length of die angle.	Ratio or tangent.	Angle of which ratio is tangent.	
Mm.	*Mm.*		°	′	*Mm.*	*Mm.*		°	′
1.0	60	0.016	0	55	5.0	89	0.0562	3	13
1.5	60	.025	1	26	5.5	89	.0618	3	32
3.0	76	.0394	2	15	6.0	89	.0674	3	51
4.0	110	.0364	2	5	7.0	89	.0786	4	30
4.0	89	.0450	2	35	8.0	68	.1176	6	42

PRESSURES USED.

The German briquetting press was built to give a working pressure of 14,000 to 28,000 pounds per square inch, and as the area of the face of a briquet was 15.55 square inches, the total pressure developed by the machine was 217,700 to 435,400 pounds. The pressure actually used in the different tests could not be determined, and could be approximated only when the material stalled the machine, the pressure then being maximum.

INCIDENTAL CHEMICAL TESTS.

MOISTURE CONTROL.

As it was impossible for the chemical laboratory of the fuel-testing plant to make moisture tests for the briquetting section and report results within the same day, a method of determining moisture with sufficient accuracy for control purposes was devised by F. M. Stanton, chemist in charge of the laboratory. The procedure was as follows: Fifty grams of coarsely crushed lignite were placed in a distilling flask of about 200 c. c. capacity, covered with 70 c. c. kerosene, and heated over a gas flame. The moisture driven off was condensed in a Liebig condenser and run into a tall 25-c. c. measuring cylinder or burette. The distillation was carried on until a thermometer in the flask showed a final temperature of 350° F. The cubic centimeters of water in the measuring cylinder were noted when the thermometer

in the flask registered 250° F., 300° F., and 350° F., and the percentage of moisture in the sample was taken as the percentage of moisture distilled at 300° F. Of course, some of the kerosene distilled over, but it readily separated from the water and the quantity of the latter in the measuring cylinder could be accurately read.

<div style="text-align:center">EXTRACTION TEST.</div>

To determine the percentage of bitumen or natural binding material in the raw or briquetted lignite, samples were extracted with carbon bisulphide in a Soxhlet apparatus in the following manner:

Five grams of the finely ground material were weighed in an extraction thimble and extracted in a flask that had been dried for one-half hour at 108° C., cooled in a desiccator, and weighed. After the material had been in the extractor five hours the carbon bisulphide in the flask was distilled off and recovered in the Soxhlet extractor; the flask and its contents were dried at 108° C. for one hour, cooled and weighed, and the percentage of material extracted was calculated from the weight of the residue. The result was computed to a moisture-free basis for convenience of comparison and the results of the extraction tests herein reported are on this basis.

Since the percentage of material soluble in carbon bisulphide indicates the percentage of natural binder in the lignite, the results of an extraction test are valuable aids in determining whether a sample under investigation can be briquetted without adding artificial binder. If it can not be, the results are a guide in determining how much binder must be added to make satisfactory briquets.

The results of extraction tests of the lignites briquetted are shown in the following table:

Extraction-test results.

Sample used.	Number of samples tested.	Average per cent of dry sample soluble in CS$_2$.	Remarks.
Pittsburg:			
No. 7 (Rockdale, Tex.)	2	1.20	No satisfactory briquets made.
No. 8 (Lytle, Tex.)	3	2.01	Satisfactory briquets made.
No. 9 (Calvert, Tex.)	4	1.24	No satisfactory briquets made.
No. 11 (Scranton, N. Dak.)	4	1.72	Satisfactory briquets made.
No. 13 (Lehigh, N. Dak.)	13	1.43	Difficult to briquet.
No. 14 (Ione, Cal.)	7	7.60	Satisfactory briquets made.
No. 15 (Vanderwalker, N. Dak.)	2	1.08	No satisfactory briquets made.

The following important conclusions, some of which are indicated by the table, can be drawn from the results of the briquetting and the extraction tests described above:

1. Lignites containing less than 1.4 per cent of matter soluble in carbon bisulphide (calculated to a moisture-free basis) have not been

briquetted with the German machine, nor with any other machine, without the addition of a binder.

2. Lignites containing 1.4 to 1.5 per cent of matter soluble in carbon bisulphide are difficult to briquet, and further tests are needed to determine whether entirely satisfactory briquets can be made from them with the German machine.

3. The few lignites tested that contained more than 1.5 per cent of matter soluble in carbon bisulphide were briquetted with the German machine without binder.

4. The percentage of moisture that the dried lignite must contain to give satisfactory briquets with the German machine is, within limits, proportional to the percentage of matter soluble in carbon bisulphide. Hence, if two lignites have the same ash content the one that is richer in bitumen may be dried more and will give briquets of higher heat value (because of the lower moisture content) than the other.

TESTS TO WHICH BRIQUETS WERE SUBJECTED.

PHYSICAL TESTS.

Samples of the better lots of briquets made were subjected to the drop test and the tumbler test to determine their cohesive strength and to show their ability to endure handling.

DROP TEST.

Fifty pounds of briquets were placed in a drop-bottom box, 24 inches square and 12 inches deep inside, that was supported 6 feet above a concrete floor. The briquets were suddenly dropped on this floor; then the pieces were gathered up and those that were held by a 1-inch screen (square holes) were returned to the box and dropped again. The floor was swept clean before each drop. This procedure was repeated five times, after which the weight of pieces that would not pass through the screen was determined. The percentage that the weight of these pieces bore to the original weight is here reported as " per cent held by 1-inch screen," and the difference between this figure and 100 per cent is reported as " per cent passed by 1-inch screen."

TUMBLER TEST.

A weighed quantity of the briquets (as nearly as possible 50 pounds) was placed in a tumbler, a horizontal sheet-steel cylinder, and rotated 2 minutes at a uniform speed of 28 revolutions per minute. The contents of the tumbler were then sized by a 1-inch mesh screen, and the portion that passed through was screened through a

10-mesh sieve. The weight of the pieces held by each screen was determined and the " percentage held " computed and reported as in the drop test.

WEATHERING TEST.

To determine the comparative weather-resisting qualities of the lignite briquets and the samples of lignite from which they were made, small piles of each lot of satisfactory briquets and lumps of the raw lignites were exposed to the action of sun, wind, and rain on the roof of the briquet building from September, 1909, to May, 1910. Plates VI to XI, made from photographs taken at various intervals up to 286 days, show the different stages of weathering. The length of time the briquets had been exposed before examination and the condition of the briquets when examined are stated in the tabulated results of tests. The key to the conditions designated A, B, C, D, and E is that stated in Bulletins 332 and 385 of the United States Geological Survey and is as follows:

A. Briquets practically in same condition as when put out. Surfaces show no signs of erosion or pitting. Briquets hard, with sharp edges, and fracture same as that of new briquets.

B. Shape of briquets unchanged. Surfaces of those on top of pile have lost luster, with evidences of pitting, corners and edges worn off by erosion. All briquets firm, with fracture practically the same as that of new briquets.

C. Top briquets appear similar to those in condition B, and show signs of further disintegration, having lost original sharp fracture. Erosion more evident on all briquets on outside of the pile. Inside briquets still firm, retaining original characteristics.

D. Top briquets so badly disintegrated that they crumble to pieces on handling. Briquets in center of pile show signs of disintegration; luster of surfaces gone, edges soft, and break easily in the hand. Fracture not so sharp as when newly made, but briquets firm and handled without breaking.

E. Entire pile disintegrated. In many cases the only briquets retaining their original shape are those protected from the weather. Briquets can not be handled safely, but crush easily in the hand.

DETAILS OF TESTS.

PITTSBURG No. 7.

A sample shipment, 3 cars, of lignite from the Big Lump Mine, 3½ miles northeast of Rockdale, Milam County, Tex., was designated Pittsburg No. 7.

House-heating boiler tests Nos. H23, H24, H30, H45, and H46 were made on this fuel, but the larger part of the shipment was used in preliminary briquetting experiments to adjust the drier, cooler, and press of the German plant. This lot was the first to arrive at the testing station, considerable difficulty was experienced in making it

into briquets and the shipment was exhausted before satisfactory results were obtained. It is hoped that further tests of this lignite may be made under more favorable conditions.

The following proximate analyses show the changes in composition of the sample during transportation from the mine to the plant, a period of 29 days, and after storage at the plant for 17 and 38 days, respectively.

Proximate analyses of lignite from Rockdale, Tex.

	Mine sample.	Car sample.	Plant samples.	
			After 17 days.	After 38 days.
Date taken	Feb. 1	Mar. 1	Mar. 18	Apr. 8
Laboratory No	7270	7350	7433	7554
Air-drying loss per cent	31. 50	25. 10	25. 70	25. 30
Moisture do	35. 30	33. 38	31. 72	30. 98
Volatile matter do	26. 22	27. 44	26. 81	29. 04
Fixed carbon do	29. 58	29. 62	31. 97	30. 41
Ash do	8. 90	9. 56	9. 50	9. 57
Sulphur do	. 76	. 94	. 91	. 92
Heat value B. t. u.	6,898	7,189	7,423	7,301

Mr. Lehmann, the representative of the German company that furnished the lignite-briquetting plant, remained at Pittsburg until the plant was in good working condition. The tests of the first sample of lignite were therefore under his direction. Most of these tests were preliminary and it was impossible to obtain a complete record of them, so only a general statement of conditions and results can be given.

The briquet material in the various tests contained different proportions of water, ranging from 2.3 to 11.2 per cent, and different pressures, from very light to the heaviest possible, were applied to it. From some of the tests the briquets were poorly formed, rough, and scaly, but were fairly strong; from other tests the briquets were well formed but weak.

Only one cohesion (drop) test was made on the briquets obtained, because most of the tests gave only pieces of briquets. The results of this test were as follows: Held by 1-inch screen, 24 per cent; through 1-inch screen, 76 per cent.

The best briquets were made by using material that contained 11.2 per cent moisture and applying a rather light pressure. The results seemed to show that for best results with the German machine the ground and dried lignite should contain between 8 and 12 per cent moisture, and the pressure used should be moderate, about that obtained by using a set of dies so ground that in a length of about 80 mm. the decrease in height would be 3 to 4 mm.

As a general conclusion, it may be said that this lignite is deficient in natural binding material, and although it can be briquetted without artificial binder on a machine of the type used, such a machine did not make briquets of satisfactory form and strength from it. To determine the best conditions for briquetting, further tests are needed. It is probable that the lignite will make entirely satisfactory briquets if an artificial binder and a different type of press are used.

PITTSBURG No. 8.

A sample shipment, 2 cars, of ½-inch lump lignite from the Carr mine No. 3, 2 miles southwest of Lytle, Medina County, Tex., was designated Pittsburg No. 8.

This lignite had a dark-brown color. It weathered very rapidly, exposure to a single rainstorm causing lumps to crack in all directions. After it had been wet and dried a few times the sample crumbled entirely to slack.

Gas-producer test 180 and briquetting tests 293, 295, and 296 were made on this fuel, and several preliminary briquetting tests for adjusting the press.

The changes in composition of the lignite during transportation from the mines to the plant (25 days), and during storage (42 days) at the plant till used, for one of the last tests, are shown by the following proximate analyses:

Proximate analyses of lignite from Lytle, Tex.

	Mine sample.	Car sample.	Sample as used on last test.
Date taken	Feb. 5	Mar. 2	Apr. 13
Laboratory No	7330	7461	7584
Air-drying loss per cent	24.20	26.30	19.40
Moisture do	32.92	30.77	28.00
Volatile combustible do	27.42	27.36	27.50
Fixed carbon do	27.08	28.39	32.30
Ash do	12.58	13.48	12.20
Sulphur do	1.46	1.62	1.60
Heat value B. t. u	6,840	7,079	7,580

Several preliminary tests were made under the direction of Mr. Lehmann. In the first of these, with a steam pressure of 5 pounds in the drier, the percentage of moisture in the fuel was reduced from 30 per cent to 11.2 per cent. A rather low pressure in the molds produced well-formed but weak briquets.

Material containing 10 per cent moisture, and subjected to a high pressure, furnished briquets that had poor form and rough surfaces, but were much stronger than those made in the first test. The rough-

ness of surface was largely caused by steam (generated while the briquet was being formed under high pressure) that blew out around the sides of each briquet just before it left the mold. The dust blown out by the steam was disagreeable to breathe and at times formed clouds which darkened the whole room.

In the next test, material containing 8.4 per cent moisture was subjected to a high pressure. The briquets were better formed and smoother than in the previous test and were the strongest yet made from the lignite.

In the fourth test the material contained 6 per cent moisture, but the same high pressure was used. The briquets were still better, being well formed and strong. Another test, with the material containing only 3.6 per cent moisture, gave the best briquet obtained from this fuel. However, with this low moisture content the mold pressure was too great for the press, and after an hour's run the main bearing of the connecting rod became so hot that the press had to be stopped.

The following table summarizes the essential data of the tests made with this sample of lignite:

Summary of tests.

Test No.	Moisture in briquet material.	Pressure in mold.	Character of briquets.		Remarks.
			Form.	Strength.	
Preliminary	*Per cent.* 11.2	Low	Good	Weak	Pressure insufficient.
Do	10.0	High	Poor	Strong	Briquets rough.
Do	8.4	....do	Fair	...do	
Do	6.0	....do	Good	...do	Better than previous lot.
Do	3.6	....do	....do	...do	Best lot.
293	8.7	....do	....do	Good	
295	7.7	Very high	None made		Material too dry.
296	12.2	....do	Fair	Weak	Material too fine.

In the first official test (293) the material contained 8.7 per cent moisture and a high pressure was applied. About 61 per cent of the material that reached the press was coarser than $\frac{1}{16}$ inch, but practically all of this 61 per cent passed through a screen with ¼-inch meshes. The results indicate that it is well to have the material as evenly sized as possible and without much dust. If the proportion of dust is excessive, the material does not bind well and blows out of the mold when pressed. Even sizing is also desirable because it permits even drying. The writer believes that this fuel should be crushed so that it will all pass through a ¼-inch screen, and yet about 60 per cent of it will be retained on a $\frac{1}{16}$-inch screen.

In tests 295 and 296 the dies were set to give a very high pressure. In test 295 the briquet material contained 7.7 per cent moisture and was probably too dry; it did not bind but fell from the press in the form of powder, accompanied by clouds of dust.

In test 296 the dried material had 12.2 per cent moisture. The material probably contained too much dust, for the briquets crumbled easily and were not strong enough to handle.

Plates VI to XI show how the briquets from tests 293 and 296 withstood exposure to the weather.

This lignite was made into excellent briquets without the addition of any binder. The moisture content of the dried material should be between 8 and 10 per cent if a moderate pressure is used, but only about 5 per cent, or even less, if an extremely high pressure is used. For best results the writer recommends that the material be pulverized so that about 60 per cent of the particles are between ¼ inch and $\frac{1}{16}$ inch in diameter, that it go to the press containing 10 per cent moisture, and that the briquetting pressure be 20,000 pounds per square inch.

The best briquets made from this fuel had strength enough to stand handling. They took the shape of the mold well, their edges were firm, and they had jet-black, lustrous surfaces. Such briquets should make a satisfactory steam or household fuel. No steaming tests were made on either the raw or briquetted lignite. The ash content (about 17 per cent) of the briquets is considerably higher than that of good quality bituminous coal.

Briquetting this lignite should improve its heat value 30 to 40 per cent by reducing the percentage of moisture. On the assumption that in briquetting the uncombined moisture is reduced from 30 per cent to 10 per cent, 1 ton (2,000 pounds) of raw fuel will make 1,600 pounds of briquets, or 2,500 pounds of raw fuel will make 1 ton of briquets. The raw fuel has a heat value of 6,800 B. t. u. per pound and the briquetted fuel has a heat value of 9,300 B. t. u.; therefore the fuel value of the briquets is 37 per cent higher than that of the raw fuel. Moreover, the briquets have the following additional advantages over raw fuel:

(a) Being of uniform size, they burn more freely and give off less smoke, a decided merit when used as a household fuel in a residence district.

(b) The briquets resist the effects of the weather much better than the raw fuel, and therefore can be stored for a longer time without serious deterioration. The briquets are not, however, much more waterproof than the raw fuel, and should be stored under cover; there they will remain in perfect condition for several months at

least, while the raw fuel under similar conditions will disintegrate rapidly.

(c) The cost of transporting the briquetted fuel should be only 80 per cent of the cost of transporting enough raw fuel to furnish the same heat value.

Briquetting tests.

	Test 293.	Test 295.	Test 296.
Size as shipped	¾" lump.	¾" lump.	¾" lump.
Size as used:			
Over ¼ inch .... per cent..	0.5	0.5	0.5
⅒ inch to ¼ inch ....do....	30.5	18.0	18.0
⅒ inch to ⅒ inch ....do....	30.0	28.5	28.5
⅒ inch to ⅒ inch ....do....	24.5	21.0	21.0
Through ⅒ inch ....do....	14.5	32.0	32.0
Details of manufacture:			
Machine used	German.	German.	German.
Briquetting temperature ....°F..	90	94	101
Binder used	None.	None.	None.
Tangent of die angle	⅚	⅚	⅚
Steam pressure on drier ....pounds..	13	15	11
Weight of—			
Fuel briquetted ....do....	11,440	None.	4,840
Briquets, average ....do....	0.9	....	0.7
Heat value per pound:			
Fuel as received ....B. t. u..	7,580	7,395	....
Briquets ....do....	9,448	....	9,223
Moisture in briquet mixture ....per cent..	8.73	7.68	12.17
Drop test (1-inch screen):			
Held ....do....	44.	(a)	(b)
Passed ....do....	66.	....	....
Tumbler test (1-inch screen):			
Held ....do....	37.	....	(b)
Passed ....do....	63.	....	....
Fines through 10-mesh sieve ....do....	74.	....	....
Weather test:			
Time exposed when examined ....days..	66	....	....
Condition when examined	D	....	....

a No briquets.
b Briquets too weak for cohesion test.

PROXIMATE ANALYSES OF BRIQUETS.

Laboratory No	7,583	7,623	....
Moisture ....per cent..	8.07	9.96	....
Volatile matter ....do....	37.31	37.84	....
Fixed carbon ....do....	35.87	35.99	....
Ash ....do....	18.75	16.21	....
Sulphur ....do....	1.97	1.98	....

PITTSBURG No. 9.

A sample shipment, 3 cars, of ¾-inch lump lignite from the Calvert mine, 6 miles west of Calvert, Robertson County, Tex., was designated Pittsburg No. 9.

Gas-producer tests 181 and 182, house-heating boiler tests H41 and H43, and briquet tests 297, 320, 321, 323, 327, and 328 were made on the raw lignite.

The following proximate analyses show the changes in composition of this lignite during transportation from the mine to the plant, a period of 26 days, and in storage at the plant for 81 days until used for the last test. The last column gives an average of 6 analyses made on different dates.

Proximate analyses of lignite from near Calvert, Tex.

	Mine sample.	Car sample.	Sample as used on last test.	Average of 6 samples.
Date taken	Mar. 6	Apr. 1	June 21	....
Laboratory No	7,403	7,513	7,950	....
Air-drying loss ....per cent..	29.30	25.40	12.10	13.17
Moisture ....do....	34.33	29.62	28.50	24.01
Volatile matter ....do....	25.94	27.60	29.07	29.75
Fixed carbon ....do....	30.93	29.37	35.74	34.74
Ash ....do....	8.80	13.41	11.69	11.50
Sulphur ....do....	.95	.98	.82	.91
Heat value ....B. t. u..	7,214	7,040	8,089	8,021

Test 297 did not yield any briquets. Apparently the pressure in the mold was excessive; there may have been too little moisture in the material or the die angle may have been too great.

In test 320 a high pressure was used. The briquets were poorly formed and too weak to handle. The moisture content of the material was evidently too high for the pressure used. Much dust was blown out around the sides of each briquet.

In test 321 the same pressure was used, but the material was still too moist and no satisfactory briquets were obtained. The briquets made had poor forms and were too weak to handle.

The material was drier in test 323 than in tests 297, 320, and 321, and contained only 3 per cent moisture when it reached the machine. It was also finer. This material, however, stalled the press. After several attempts to operate the machine the test was stopped and the material remaining in the hopper was thrown away.

In test 327 the material was dried less than in test 323, and contained 4.6 per cent moisture when it reached the machine. The dies were changed so as to give less pressure. The briquets obtained were better than those made in test 323, but although they had good form they lacked strength, and crumbled when handled.

In the next test (328) the percentage of moisture in the briquet material was raised to 6.4 per cent with beneficial results. The same pressure was used as in test 327. The briquets were the best so far obtained, but they were not strong enough to handle. The test was not completed, however, for a strong steel brace having a cross section of 3 by $5\frac{1}{4}$ inches snapped without warning and put the press out of commission until another brace could be forged. The tests were suspended before other pressures could be tried.

Following is a summary of the most important features of the tests on this sample of lignite:

Summary of tests.

Test No.	Moisture in briquet material.	Pressure in mold.	Character of briquets.		Remarks.
			Form.	Strength.	
	Per cent.				
327...	4.6	High.	Good.	Weak.	Too much moisture.
328...	6.4	....do.	....do.	....do.	Better than test 327.
297...	7.0	....do.	None made.		Too much pressure.
323...	3.0	Very high.	....do.		Stalled machine; too little moisture and too much pressure.
321...	6.4	....do.	Poor.	Weak.	Too much moisture and dust.
320...	9.47	....do.	....do.	....do.	Do.

It will be seen that the moisture content in the briquet material varied from 3 per cent to 9¼ per cent. Two different pressures were used, but, although some of the tests gave briquets of good form, no briquets were of satisfactory strength.

To yield best results with the German machine, this lignite should be ground so that all of it will pass a ¼-inch screen, but about 60 per cent will be retained by a $\frac{1}{10}$-inch screen, and should be dried till it contains 10 per cent moisture. The die angle should be small enough to give a moderate pressure. However, the indications are that this lignite does not contain enough natural binder to make good briquets on the German press, and it should be tested with a little artificial binder on a press similar to the English machine. The writer is inclined to doubt if this lignite can be briquetted at all without the addition of binding material. However, further tests should be made before a final conclusion is reached.

Briquetting tests.

	Test 297.	Test 320.	Test 321.	Test 323.	Test 327.	Test 328.
Size as shipped	¼″ lump.	¼″ lump.	¼″ lump.	¼″ lump.	¼″ lump.	¼″ lump.
Size as used:						
Over ¼ inch........per cent..	2.0	3.0	2.5	2.5	2.0	2.0
$\frac{1}{10}$ inch to ¼ inch........do....	18.0	23.0	25.0	30.0	31.5	30.5
$\frac{1}{10}$ inch to $\frac{1}{10}$ inch........do....	30.0	28.0	28.5	28.5	29.0	30.5
$\frac{1}{10}$ inch to $\frac{1}{10}$ inch........do....	27.0	22.5	21.0	20.5	19.5	19.0
Through $\frac{1}{10}$ inch........do....	23.0	23.5	23.0	18.5	18.0	18.0
Details of manufacture:						
Machine used	German.	German.	German.	German.	German.	German.
Briquetting temperature.......°F..	84	100	102	97	93	116
Binder used	None.	None.	None.	None.	None.	None.
Tangent of die angle	$\frac{1}{10}$	$\frac{1}{10}$	$\frac{1}{10}$	$\frac{1}{15}$	$\frac{1}{10}$	$\frac{1}{12}$
Steam pressure on drier......pounds..	10	4	10	15	10	12
Weight of—						
Fuel briquetted........do....	None.	None.	None.	None.	None.	None.
Briquets, average........do....						
Heat value per pound:						
Fuel as received........B. t. u..	7,920	7,925	8,114	7,900	8,176	8,069
Briquets........do....		9,574	9,929		10,028	
Moisture in briquet mixture.....per cent..	6.98	9.47	6.40	3.0	4.6	6.4

PITTSBURG No. 11.

A car of run-of-mine lignite from the Scranton Mine, Scranton, Bowman County, N. Dak., was designated Pittsburg No. 11. This lignite had a dark-brown color, almost black, but became somewhat lighter colored after drying.

Producer-gas test 187 and briquetting tests 312, 317, 318, 319, and 322 were made on the raw lignite. House-heating boiler tests H86 and H87 were made on briquets from briquetting test 322.

The following table shows the changes in composition of this lignite during transportation from the mine to the plant, a period of 38 days, and during storage at the plant until used for the last briquetting test, a period of 50 days. The last column gives an average of 5 proximate analyses made on different dates:

Proximate analyses of raw lignite.

	Mine sample.	Car sample.	Sample used on last test.	Average of 5 samples.
Date taken	Mar. 20	Apr. 23	June 12	....
Laboratory No.	7499	7677	7942	....
Air-drying loss.....................per cent..	36.00	27.50	22.70	20.7
Moisture.....................do....	41.43	38.81	32.30	32.68
Volatile matter.....................do....	23.86	25.48	18.81	26.24
Fixed carbon.....................do....	28.45	27.29	40.71	33.45
Ash.....................do....	6.26	8.42	8.18	7.62
Sulphur.....................do....	.74	.97	.85	.93
Heat value.....................B. t. u..	6,241	6,347	7,160	7,243

Test 312, of material dried till it held 10.6 per cent moisture, furnished some fairly strong briquets during the latter half of the run when conditions had become constant. The shape of these briquets was good, their surfaces were smooth, and their edges were sharp. They could be handled without too much breakage. The best briquets were made by running the machine at moderate speed, about 60 revolutions per minute.

Test 317, in which the material was dried until it contained 11 per cent moisture, and the pressure was heavier than in test 312, failed to produce satisfactory briquets. Those formed were too weak to handle, and crumbled to pieces soon after leaving the mold. The chemical analysis reported was made on the broken briquets.

Test 318, in which the material contained 11.7 per cent moisture and the pressure was the same as in test 317, furnished some fair briquets during the latter part of the run, but they were not strong enough to handle. As in test 317, pieces of briquets were analyzed.

Test 319, in which the material contained 15 per cent moisture, produced excellent briquets; they had smooth surfaces, sharp edges, and were strong enough to bear handling.

The conditions during test 322 differed from those during test 319 only in the moisture content of the material. The briquets were strong and well formed, with smooth, polished surfaces.

Plates VI to XI show how briquets from tests 312, 319, and 322 withstood exposure to the weather.

This lignite was made into good briquets without the use of a binder. Satisfactory briquets can be made by drying the ground lignite till it contains 11 per cent moisture, and better briquets can be made if the moisture content is about 15 per cent. The indications are that material containing more than 15 per cent moisture can be worked on this press and will probably furnish stronger briquets than any mentioned in this report. Unfortunately the control of the drier at the Pittsburg plant did not permit the material, if dried at all, to contain more than 15 per cent moisture. This defect can be remedied, however, by changing the proportions or the speed of the drier.

Data relating to the test made with this lignite are summarized in the table appended.

Briquetting tests.

	Test 312.	Test 317.	Test 318.	Test 319.	Test 322.
Size as shipped....................................	r. o. m.	r. o. m.	r. o. m.	r. o. m.	r. o. m.
Size as used:					
Over ¼ inch..............................per cent..	2.00	3.00	1.00	3.00	1.50
₁₀ inch to ¼ inch......................do....	21.00	29.50	17.50	32.00	29.00
₁₀ inch to ₁₀ inch......................do....	28.00	25.00	32.50	29.50	29.00
₁₀ inch to ₁₀ inch......................do....	26.00	16.50	22.00	16.50	20.00
Through ₁₀ inch......................do....	23.00	26.00	27.00	19.00	20.50
Details of manufacture:					
Machine used............................	German.	German.	German.	German.	German.
Briquetting temperature.............°F.	103	98	101	99	102
Binder used............................	None.	None.	None.	None.	None.
Tangent of die angle....................	₁₀	₁₀	₁₀	₁₀	₁₀
Steam pressure on drier.............pounds..	10	10	5	4	4
Weight of—					
Fuel briquetted......................do....	4,383	a None.	2,000	4,000	6,300
Briquets, average....................do....	1.00	....	1.00	1.03	1.07
Heat value per pound:					
Fuel as received......................B.t.u..	7,265	7,270	7,510	7,034	7,160
Briquets..............................do....	9,434	9,470	9,189	9,184	9,445
Moisture in briquet mixture...........per cent..	10.60	11.06	11.73	14.96	12.60
Drop test (1-inch screen):					
Held..................................do....	42	....	....	44	34
Passed................................do....	58	....	....	56	66
Tumbler test (1-inch screen):					
Held..................................do....	36	....	....	43	37
Passed................................do....	64	....	....	57	63
Fines through 10-mesh sieve.............do....	65	....	....	56	59
Weather test:					
Time exposed when examined............days..	66	....	....	66	66
Condition when examined..............	E	....	....	E	D

a The few briquets made fell to pieces when handled.

PROXIMATE ANALYSES OF BRIQUETS.

Laboratory No..	7807	7886	7893	7901	7944
Moisture.................................per cent..	10.76	10.70	12.09	12.48	11.93
Volatile matter.............................do....	38.97	38.95	38.11	38.92	36.87
Fixed carbon...............................do....	40.94	40.69	39.68	39.47	41.37
Ash.......................................do....	9.33	9.66	10.12	9.13	9.83
Sulphur...................................do....	1.22	1.20	1.27	1.20	1.21

PITTSBURG No. 13.

This sample consisted of 1 car of run-of-mine lignite from the Lehigh mine, Stark County, N. Dak. It was used in making gas-producer test 184, and briquetting tests 294, 298, 299, 300, 301, 302, 303, 304, 305, 306, and 307.

The following table shows the changes in composition of this fuel during transportation from the mine to the plant, a period of 12 days, and during storage at the plant until used for the last briquet test, a period of 30 days. The last column is an average of 8 proximate analyses of samples used on different dates.

Proximate analyses of raw lignite.

	Mine sample.	Car sample.	Sample as used on last test.	Average of 8 samples.
Date taken	Mar. 29	Apr. 10	May 10	....
Laboratory No	7537	7553	7752	....
Air-drying loss .... per cent..	37.8	34.3	28.9	28.68
Moisture .... do....	42.04	40.23	38.95	38.08
Volatile matter .... do....	23.40	24.89	24.44	24.86
Fixed carbon .... do....	27.67	28.03	29.38	29.74
Ash .... do....	6.89	6.85	7.23	7.32
Sulphur .... do....	.68	.62	.91	.90
Heat value .... B. t. u..	6,079	6,246	6,327	6,579

The ground and dried lignite used in test 294 contained 11 per cent moisture. It made well-formed briquets that had rather brittle edges and cracked sides. They were strong enough to endure careful handling and were the strongest lot made from this fuel.

In tests 298, 299, 300, 301, 302, 303, and 304 the moisture content and the pressure were varied in an endeavor to get the best conditions, but the few briquets made were too weak to handle and were not kept.

In test 305 the material contained about 15 per cent moisture; some of the briquets were strong enough to endure careful handling, but they were softer than those from test 294 and crumbled more easily. Apparently the material was too coarse and contained too much moisture. The briquets were, however, a great improvement over those from tests 298 to 304, inclusive.

Tests 306 produced some fairly good briquets, there being little choice between the lot and those from test 305. Apparently the moisture content of the dried material was too high. The briquets crumbled easily and when struck gave a dull sound instead of the sharp, metallic ring of good briquets. The briquets from tests 305 and 306 were mixed in storage, and the cohesion tests were made from a mixed sample.

The briquets made by test 307 had better forms than those from any other test on this fuel, but were not so strong as those from tests 294, 305, or 306.

This lignite can be made into briquets but further tests are desirable to determine the best conditions. Fine grinding is a requisite. About 10 to 12 per cent moisture in the material seems desirable and a heavy pressure is necessary. The proportion of natural binder in the lignite being rather low, briquets made without adding artificial binder are likely to be weak. Probably the use of a small proportion, perhaps 2 to 4 per cent, of artificial binder and a different type of press would give better briquets.

Summary of briquetting tests.

	Test 294.	Test 298.	Test 299.	Test 300.	Test 301.
Size as shipped..	r. o. m.	r. o. m.	r. o. m.	r. o. m.	r. o. m.
Size as used:					
Over ¼ inch.............................per cent..	0.0	1.0	0.0	0.0	0.5
⅟₁₆ inch to ¼ inch..............................do....	27.7	21.0	20.0	20.0	12.0
⅟₃₀ inch to ⅟₁₆ inch..............................do....	40.0	31.5	36.0	36.0	28.5
⅟₆₀ inch to ⅟₃₀ inch.............................do....	22.3	25.5	25.0	25.0	27.0
Through ⅟₆₀ inch.............................do....	10.0	21.0	19.0	19.0	32.0
Details of manufacture:					
Machine used..............................:	German.	German.	German	German.	German.
Briquetting temperature.......................°F..	90	75	75	75	68
Binder used.................................	None.	None.	None.	None.	None.
Tangent of die angle.........................	⅝	⅝	⅝	⅝	⅝
Steam pressure on drier.................pounds..	20	20	20	20	15
Weight of—					
Fuel briquetted........................do....	2,840	None.	*a* None.	*a* None.	*a* None.
Briquets, average......................do....	0.775				
Heat value per pound:					
Fuel as received.....................B. t. u..	6,311	6,586	6,840	6,840	6,653
Briquets.................................do....	9,191				
Moisture in briquet mixture...............per cent..	11.13	9.19	9.88	9.88	9.19
Drop test (1-inch screen):					
Held......................................do....	25				
Passed....................................do....	75				
Tumbler test (1-inch screen):					
Held......................................do....	30				
Passed....................................do....	70				
Fines through 10-mesh sieve.............do....	67				

	Test 302.	Test 303.	Test 304.	Test 305.	Test 306.	Test 307.
Size as shipped.............................	r. o. m.	r. o. m.	r. o. m.	r. o. m.	r. o. m.	r. o. m.
Size as used:						
Over ¼ inch..................per cent..	0.5	0.5	0.5	2.0	0.8	0.8
⅟₁₆ inch to ¼ inch..................do....	18.0	20.0	21.0	22.5	21.5	21.5
⅟₃₀ inch to ⅟₁₆ inch..................do....	24.0	34.5	31.5	30.5	32.2	32.2
⅟₆₀ inch to ⅟₃₀ inch..................do....	26.0	25.5	24.5	21.5	22.5	22.5
Through ⅟₆₀ inch..................do....	31.5	19.5	22.5	23.5	23.0	23.0
Details of manufacture:						
Machine used.........................	German.	German.	German.	German.	German.	German.
Briquetting temperature..........°F..	78	74	88	81	85	102
Binder used...........................	None.	None.	None.	None.	None.	None.
Tangent of die angle...................	⅝	⅝	⅝	⅝	⅝	⅝
Steam pressure on drier......pounds..	10	10	10	8	12	16
Weight of—						
Fuel briquetted..............do....	*b* 500	*b* 700	*b* 1,950	1,880	2,138	700
Briquet, average..............do....			0.9	0.77	0.77	0.82
Heat value per pound:						
Fuel as received..............B. t. u..	6,586	6,397	6,520	6,995	6,327	6,327
Briquets.........................do....	9,504	9,691	9,684	8,995	9,490	9,698
Moisture in briquet mixture.....per cent..	9.81	11.02	11.56	14.80	12.12	9.29
Drop test (1-inch screen):						
Held..........................do....				16.00	16.00	5.00
Passed........................do....				84.00	84.00	95.00
Tumbler test (1-inch screen):						
Held..........................do....				17.00	17.00	7.00
Passed........................do....				83.00	83.00	93.00
Fines through 10-mesh sieve....do....				60.00	60.00	60.00

a The few briquets made were too weak to handle.
b Briquets were scrapped, as they were too weak to handle.

PROXIMATE ANALYSES OF BRIQUETS.

	Test 294.	Test 301.	Test 302.	Test 303.	Test 304.	Test 305.	Test 306.	Test 307.
Laboratory No.	7611	7702	7703	7719	7723	7726	7755	7751
Moisture................per cent..	8.56	8.30	10.87	10.26	10.18	12.10	11.41	10.29
Volatile matter.............do....	37.51	37.00	36.83	38.79	37.82	35.00	36.52	37.14
Fixed carbon...............do....	41.23	42.80	42.71	42.35	43.00	44.10	42.55	43.93
Ash.......................do....	12.70	11.90	9.59	8.60	9.00	8.80	9.52	8.64
Sulphur...................do....	2.24	1.90	1.58	1.12	1.21	1.35	1.40	1.02

PITTSBURG No. 14.

A sample lot, 3 cars, of run-of-mine lignite from the Ione mine, at Ione, Amador County, Cal., was designated Pittsburg No. 14.

Briquetting tests 308, 309, 310, 311, 313, 314, 315, and 329 were made on it. Gas-producer test 185 and house-heating boiler test H90 were made on the raw lignite, and gas-producer test 188 and house-heating boiler tests H88 and H89 were made on the briquets.

When received at the plant this lignite was light brown in color. The pieces could be easily polished by rubbing and had a peculiar waxy feel, like that of soapstone. It was evident from a casual inspection that the lignite was rich in binding material. The results of subsequent tests and analyses confirmed this fact.

The following table shows the changes in composition of this fuel after storage at the plant for 68 days, until used for the last briquet test. The last column gives the average of proximate analyses of 8 samples used for tests on different dates. No mine sample was taken.

Proximate analyses of raw lignite.

	Car sample.	Sample as used on last test.	Average of 8 samples.
Date taken.	Apr. 22.	June 29.	....
Laboratory No.	7621	8019	....
Air-drying loss.....................Per cent..	32.3	22.7	26.09
Moisture.............................do.....	39.46	27.97	34.52
Volatile matter......................do.....	29.50	34.54	33.84
Fixed carbon.........................do.....	17.55	22.66	18.61
Ash.................................do.....	13.49	14.83	13.02
Sulphur.............................do.....	.97	1.58	1.08
Heat value..........................B. t. u..	6,080	7,546	6,764

In the first test (308) of this sample of lignite, the press worked much more easily than in the tests of Texas and North Dakota lignites. The dried material contained about 9.75 per cent moisture and the dies were set to give a high pressure. The briquets had rough surfaces, especially at the edges, but were of good shape. The cohesion test showed them to be stronger than the briquets made from

any other lignite, in fact they were surpassed in strength only by those made from the same lignite in test 329.

In test 309 the briquets were of excellent shape as they left the press, but on slight handling most of them broke in two along a shearing plane that extended diagonally from one long edge to another. Investigation indicated that this weakness resulted from the material being too dry to flow perfectly in the mold.

In the next test (310) the moisture content of the briquet mixture was 1 per cent higher (8½ per cent) and the shearing was practically eliminated, although there were still some signs of it. On account of this defect none of the briquets from tests 309 and 310 were saved; the pieces were scrapped, and no cohesion tests were made.

Test 311 was made to see if weathering injured the briquetting qualities of this lignite. The material used had been spread on the ground back of the briquet building for 22 days and had become fine slack. In comparison with the car sample the only change shown by proximate analysis was a smaller percentage of moisture. Apparently the weathering did not affect the briquetting qualities at all, for the test produced briquets having good shapes and surfaces and satisfactory strength.

In test 313 the moisture in the briquet material was a little over 9 per cent, and a set of dies, ground to give a very heavy pressure, was used. The briquets were the weakest of any made from this lignite. Their lack of strength may have resulted in part from the dies being new, since dies work better after being polished by use.

Tests 314 and 315 were made to determine if better briquets could be obtained by passing the undried material through a screen having $\frac{5}{16}$-inch openings. The undried material for test 314 was not screened, but that for 315 was screened. With the same steam pressure in the drier, the dried material contained 14.6 per cent moisture in test 314 and only 10.13 per cent in test 315. The two lots of briquets had satisfactory strength, but both the drop and tumbler tests showed that the screened material made the stronger briquets, the gain in strength being 12 per cent by the drop test and 26 per cent by the tumbler test. The two lots, however, did not differ much in general appearance, both being well formed and smooth.

Test 329 furnished the best lot of briquets made from this lignite. There was 10 per cent moisture in the briquet material; the pressure used was high, but lower than in tests 313, 314, and 315. The briquets had well-polished surfaces, and were the strongest made from any of the lignites named in this report. A "cohesive strength" of 71 per cent was shown by the drop test and 68 per cent by the tumbler test.

This lignite briquets very easily, since it contains more than enough natural binder. Weathering to slack does not reduce its briquetting properties appreciably. Excellent briquets were made with the German press by drying the ground lignite till it contains from 8½ to 15 per cent moisture. The best briquets will be obtained when the material is ground so that all of it passes a ¼-inch screen and 40 per cent passes a $\frac{1}{16}$-inch screen, when it contains 10 to 12 per cent moisture, and when it is subjected to a moderately high pressure. An extremely high pressure does not give the best results and increases the cost of briquetting. The right pressure can be had by using a set of dies so ground that the tangent of the die angle is $\frac{6}{85}$.

The following is a summary of the principal features of the tests on this sample:

Summary of tests.

Test No.	Moisture in briquet material.	Pressure in mold.	Character of briquets.		Remarks.
			Form.	Strength.	
	Per cent.				
308	9.74	High..........	Good..........	Very good....	Sides slightly cracked.
309	7.78	.....do..........	Excellent......	Weak..........	Sheared diagonally.
310	8.51	.....do..........	Good..........	Good..........	No shearing evident.
311	7.68	.....do..........	.....do..........	.....do..........	Material too dry.
313	9.14	Very high......	.....do..........	Fair..........	Do.
314	14.61	.....do..........	Very good......	Very good.....	
315	10.13	.....do..........	.....do..........	.....do..........	
329	10.00	High..........	Excellent......	Excellent.....	

In laboratory experiments a mixture of this lignite with 25 and with 50 per cent of a Pittsburg coal made excellent briquets, and further tests should be made with the mixture on the German machine. Patents have been granted for utilizing the natural binder of certain lignites to briquet mixtures of these lignites with bituminous coal slack, and thus produce a fuel superior to either constituent without using artificial binder. Anthracite screenings can be used in place of the bituminous slack, and the substitution of such screenings would lessen the production of smoke in stoves or under boilers.

Preliminary results from gas-producer tests of raw and briquetted samples of this lignite showed that the consumption of fuel, as fired per hour per brake horsepower developed, was 4.06 pounds for the raw lignite and only 2.84 pounds for the briquets. The relative efficiency of the raw and the briquetted lignite as boiler fuel was roughly shown by house-heating boiler tests H88, H89, and H90. Each pound of raw lignite evaporated 2.82 pounds of water from and at 212° F., and each pound of briquets evaporated 3.23 pounds.

The briquets resisted weathering well; samples showed little change after exposure for several months to autumn and winter weather (see Pls. VI to XI).

Briquetting tests.

	Test 308.	Test 309.	Test 310.	Test 311.	Test 313.	Test 314.	Test 315.	Test 329.
Size as shipped	r. o. m.	r. o. m.	r. o. m.	r. o. m.	r. o. m.	r. o. m.	r. o. m.	r. o. m.
Size as used:								
Over ¼ inch............per cent..	2.0	8.5	2.0	2.0	6.5	10.0	5.0	8.0
¼ inch to ¼ inch............do....	18.5	21.0	18.5	18.5	29.0	33.0	29.0	29.0
¼ inch to ¼ inch..........do....	31.0	33.0	29.0	32.5	23.0	21.5	23.5	26.0
¼ inch to ¼ inch.........do....	23.5	24.0	24.5	22.5	17.5	14.5	18.5	18.0
Through ¼ inch............do....	25.0	18.5	26.0	24.5	24.0	21.0	24.0	24.0
Details of manufacture:								
Machine used......................	German	German	German	German	German	German	German	German
Briquetting temperature.....°F..	102	95	86	91	92	104	95	107
Binder used......................	None.	None.	None.	None.	None.	None.	None.	None.
Tangent of die angle.............	¾	¾	¾	¾	¾	¾	¾	¾
Steam pressure on drier.pounds..	15	15	13	15	15	5	5	7
Weight of—								
Fuel briquetted.......do....	6,875	a 1,790	2,457	3,407	2,915	13,987	8,304	9,000
Briquets, average.......do....	0.88	0.85	0.90	0.86	....	1.05	1.02	0.92
Heat value per pound:								
Fuel as received.........B. t. u..	6,422	6,829	6,556	7,090	6,545	6,545	6,491	7,546
Briquets...................do....	9,227	10,138	9,704	9,734	9,360	8,942	9,131	9,187
Moisture in briquet mixture, per cent......................	9.74	7.78	8.51	7.68	9.14	14.61	10.13	10.00
Drop test, 1-inch screen:								
Held.................per cent..	68	(a)	....	52	28.00	50	62	71
Passed.................do....	32	(a)	....	48	72.00	50	38	29
Tumbler test, 1-inch screen:								
Held.....................do....	68	(a)	....	48	....	38	64	68
Passed.................do....	32	(a)	....	52	....	62	36	32
Fines through 10-mesh sieve, per cent......................	63.5	(a)	....	65.5	....	40	45.5	68.5
Weather test:								
Time exposed when examined ....days..	66	....	....	66	66	66	66	66
Condition when examined.......	A	....	....	A	B	A	A	A

a Briquets scrapped on account of diagonal cracks in them.

PROXIMATE ANALYSES OF BRIQUETS.

Laboratory No............Per cent..	7774	7757	7773	7775	7846	7861	7864	8018
Moisture......................do....	9.07	6.66	7.85	7.34	9.17	12.66	10.40	9.82
Volatile matter...............do....	46.53	43.99	47.53	49.04	46.28	44.95	46.60	46.48
Fixed carbon..................do....	25.01	32.80	27.01	25.97	26.75	24.59	25.31	24.54
Ash..........................do....	19.39	16.55	17.61	17.65	17.80	17.80	17.69	19.16
Sulphur......................do....	1.83	1.70	1.56	1.51	1.48	1.24	1.47	1.77

TESTS ON THE LADLEY PRESS.

The briquetting section had an opportunity to make tests of this lignite with the Ladley briquetting press of the Indianapolis Pressed Fuel Co., Indianapolis, Ind. The press was of the rotary plunger type and had two rows of molds, 108 molds in each row, arranged in the heavy rim of a wheel. The machine exerted a pressure of 5,000 to 6,000 pounds per square inch. The United States Geological Survey furnished the lignite, which was dried in the Schulz drier till it contained 6.79 per cent moisture and then shipped to Indianapolis.

The tests were made as follows: Enough of the dried material to make two or three briquets was heated in an iron pail. One mold was filled as full as possible by hand; the material was then packed in

the mold with a round bar and a sledge hammer, and the mold was again filled and tamped. Then the machine was started and the briquet was formed and ejected.

METHOD OF HEATING THE MOLDS.

Hot molds were needed for these tests, but, although the molds on this machine had steam jackets, the steam piping was disconnected to keep any water that might be pocketed in the rim from freezing, so it was necessary to heat the molds in another way. In the first test a red-hot iron was put in a mold for some time. In the other tests a gasoline torch, which gave a more even heat, was used.

METHOD OF HEATING LIGNITE.

In tests 1, 4, 5, 6, 7, 8, and 9 each pailful of the material was heated by dry steam from the nozzle of a hose, the steam being taken from the dome of the boiler. The steam escaping from the nozzle was slightly superheated, and although the loss of heat from radiation was relatively large, the lignite could be heated to a temperature of 208° F. The length of the heating was from one to two and a half minutes; the temperatures obtained were from 194° to 208° F. In tests 2, 3, and 10 the material was heated over a forge fire before pressing.

SHAPE AND WEIGHT OF BRIQUETS.

The briquets had a cylindrical shape and were 2½ inches in diameter and 3 inches long. The weight of a briquet varied from 10 to 10½ ounces.

The analyses of the briquet material before and after drying, and of the briquets made from material heated by the two methods described, are given in the following table:

Analyses of lignite and briquets.

	Material.		Briquets.	
	Before drying.	After drying.	Material heated by live steam.	Material heated by forge fire.
Moisture..............................Per cent..	39.46	6.79	13.37	4.47
Volatile combustible.........................do.....	29.50	48.72	44.36	47.43
Fixed carbon................................do.....	17.55	23.49	23.48	20.23
Ash......................................do.....	13.49	21.00	18.79	21.87
Sulphur..................................do.....	.97	1.86	1.54	1.82
Heat value................................B. t. u..	6,080	9,126	8,662	9,538

The principal details of the tests are summarized as follows: •

Details of tests 1 to 10 on the Ladley press.

Test No.	Heating of material.				Remarks.
	Method used.	Time of heating.	Temperature of material before pressing.	Quality of briquets obtained.	
		Min.	*° F.*		
1	Steam jet......	(a)	(b)	Poor; too soft and dusty.	Mold too cold.
2	Forge fire......	(a)	(b)	Poor; too dry.	
3	.....do.........	(a)	199	Fair..........	Water added before heating to replace evaporation.
4	Steam jet......	(a)	199	Good.........	Improvement made.
5	.....do.........	(a)	(b)	Fair..........	Mold too cold.
6	.....do.........	1½	208	Good.........	Satisfactory briquet.
c 7	.....do.........	2	205	Excellent.....	Do.
8	.....do.........	2½	194	.....do........	Do.
9	.....do.........	1	176	Good.........	Do.
10	Forge fire......	(a)	212–230	Excellent.....	Do.

a Not noted.
b Not taken.
c A test, 7A, was made under same conditions as test 7 on the following day.

The briquets made in tests 7 and 10 had a satisfactory appearance, their surfaces being smooth and hard and their edges sharp and firm. The briquets from test 7 had fewer surface cracks than those from test 10, although both lots were smooth enough. With steam in the steam jackets the molds would be hotter and the results might be even better.

The condensation of the steam used for heating the material in test 10 increased the moisture content of the material and of the resulting briquets. For this reason the briquets from that test had a lower heat value than those from test 7, in which the material was heated over a forge fire.

The tests demonstrated that without added binding material at least one American lignite could be made into good briquets in an American press.

STOVE AND GRATE COMBUSTION TESTS OF BRIQUETS.

OBJECT OF TESTS.

′ Combustion tests of briquets of this California lignite were made at Pittsburg, Pa., in a range and in an open heating grate. The object of these tests was—

1. To study the behavior of the briquets in the fire and note: (a) Whether they fell to pieces before they were consumed; (b) the length of flame; (c) the quantity of smoke.

2. To determine the completeness of combustion as shown by the percentage of combustible matter in the refuse.

TESTS IN A RANGE.

The range used for the test was owned by Mr. Dietz, an employee of the United States Geological Survey. It had Dockash grates with openings one-half inch wide, and could burn hard or soft coal. In the first trial, the attempt was made to burn the briquets under the

same conditions as the Pittsburg coal regularly used. Some of this coal was mixed with the briquets, however, and the fire box was filled so high that proper combustion was impossible. For the next trial, most of the coal was raked from the fire box, and a fire gradually built with briquets alone. The results were excellent. It was claimed that the briquets gave a better fire than the best Pittsburg coal.

Briquets were added at half-hour intervals. The fire did not require much poking, but it was raised slightly with a slice bar when it packed too much at the bottom. This slicing did not cause excessive loss of unburned material through the grate, as was shown by the results of the test.

In five hours 32 briquets, or 32 pounds of fuel, were burned. The refuse weighed 8 pounds and was therefore 25 per cent of the fuel as fired. An analysis of the briquets showed the ash content to be 19.16 per cent.

Analysis of the refuse or " ashes " gave the following results:

Moisture . _____ 2. 52
Combustible matter_____ 33. 05
Ash (actual)_____ 64. 43

Only one-third of the refuse was combustible matter, and since the refuse was 25 per cent of the fuel fired, the loss of combustible through the grates was 33.05×25=8.3 per cent of the coal, or 11.5 per cent of the combustible fired. This loss of 8.3 per cent is low for a kitchen stove, which at best does not burn fuel with high efficiency, and compares favorably with the percentage of loss for good bituminous coal burned in such a stove.

The proximate analyses of the briquets and of the refuse from the kitchen-stove and the heating-grate tests compare as follows:

Proximate analyses of briquets and of refuse from kitchen-stove and heating-grate tests.

Material.	Briquets.	Refuse from—	
		Kitchen-stove test.	Heating-grate test.
Moisture..per cent..	9. 82	2. 52	0. 77
Volatile matter...do....	46. 48	....	....
Fixed carbon....................,..............................do....	24. 54	....	....
Ash..do....	19. 16	64. 43	72. 60
Sulphur...do....	1. 77	....	....
Heat value ....,......B. t. u..	9,187	....	....
Combustible matter...per cent..	71. 02	33. 05	26. 63

TESTS IN A HEATING GRATE.

Through the courtesy of the quartermaster's office, the author obtained the use of a heating grate in one of the vacant buildings on the arsenal grounds at Pittsburg, Pa., for testing the combustion of the briquets in a heating grate. The grate was 24 inches wide, 9

inches deep at the center, and slightly less at the sides. The grate bars were of cast iron. The bottom bars ran from the back to the front and were spaced 1 inch apart.

A fire was started in the grate with paper and a little wood, upon which were placed 25 pounds of briquets, or enough to fill the grate to the top.

A thermometer was hung on the outside of the building and another on the wall of the room about 4 feet in front of and to one side of the fire and about 2 feet above the level of the grate.

The temperatures taken were not expected to furnish data of interest. The main object of the tests was to note the combustion of the briquets and whether the economic results obtained were better than from tests under steam boilers.

Observations on grate test.

Time.	Temperature.		Weight of fuel as fired.
	Outside.	Inside.	
	° F.	° F.	Pounds.
9.30 a. m.	37	51	25
9.45 a. m.	37	55	20
10.30 a. m.	36	67	20
12 noon.	34	α 65	35
1.30 p. m.	31	64	0
4 p. m.	30	60	0
5 p. m.	29	55	0

α Drop of temperature caused by opening an outside door.

No fuel was added to the fire after 12 noon. At 5 p. m., after burning five hours without attention, the fire was practically burned out.

The table shows that in seven and one-half hours 100 pounds of briquets were fired, giving 24 pounds or 24 per cent of refuse.

After the briquets were well ignited they burned freely—in fact, too freely for heating a room in moderate weather—but after they had burned an hour and a half the ash partly closed the open spaces between the grate bars and the fire became about right for moderately cold weather.

The briquets burned with a bright yellow flame, much cleaner than the smoky flame from some bituminous coals, and the chimney showed only a slight yellowish smoke even directly after firing fresh fuel. The fire was unpleasantly hot to the face at a distance of 8 feet. No unpleasant odor could be detected in the room, though the gases from burning lignite have a characteristic odor and irritate the eyes and nose.

The combustible in the refuse was only 26.63 per cent, and as there was 24 per cent of refuse, the loss of fuel through the grate bars was approximately 6 per cent of the total fuel fired. This loss is no greater than from a coking coal burned under the same

conditions. The loss through the grate of the kitchen range was approximately 8 per cént, or 2 per cent more than through the fire-place grate. The latter grate had wider spaces between the grate bars, but the fire in it did not need raking, while some raking of the kitchen range grate was necessary.

The loss in both grates, however, was less than anticipated. The lignite used is noncoking and one would naturally expect from it a larger loss of unburned material through the grate than from a coking coal.

<div align="center">CONCLUSIONS.</div>

From the observed results of these combustion tests the following conclusions may be drawn:

The briquets ignite readily, make a hot fire, and burn freely until consumed.

Little shaking or poking of the fire is needed to obtain maximum efficiency from the fuel.

The loss of unburned fuel through the grates, 6 to 8 per cent, is not excessive and could be reduced by using step grates, or grates with narrower spaces between the bars.

A grate measuring 8 by 24 inches is big enough for heating a large room with these briquets.

Under the test conditions little smoke was made; this smoke was light yellow and would not be offensive in residential districts.

The briquets should prove a satisfactory domestic fuel, and if they can be produced cheaply enough should compete with other fuels for steam production.

<div align="center">PITTSBURG No. 15.</div>

A sample consisting of one car of 3-inch lump lignite from the McClure mine, Vanderwalker, Ward County, N. Dak., was designated Pittsburg No. 15.

Briquetting tests 324, 325, 326, and 330 were made on it, but no gas-producer or steaming tests.

The changes in composition of the fuel during transportation from the mine to the plant, a period of 14 days, and during storage at the plant for 73 days, are shown below. The figures in the last column represent an average of 3 analyses made on different dates.

Proximate analyses of raw-fuel lignite.

	Mine sample.	Car sample.	Sample as used on last test.	Average of 3 samples.
Date taken	Apr. 3	Apr. 17	June 29	
Laboratory No	7587	7631	8020	
Air-drying loss........per cent	28.90	25.60	18.30	15.83
Moisture........do	36.64	34.30	29.09	27.94
Volatile matter........do	22.64	23.10	27.13	27.12
Fixed carbon........do	30.74	29.93	34.88	34.99
Ash........do	9.98	13.67	8.90	9.95
Sulphur........do	.45	.52	.56	.54
Heat value........B. t. u.	6,394	6,284	7,385	7,864

Dried lignite containing 7.4 per cent moisture was used for tests 324 and 325. In test 324 a set of dies, used in test 323, gave the heaviest pressure the machine would stand. The material stalled the machine, the end of a stamp broke, and no briquets were made. Another set of dies giving less pressure was used for test 325 on the same lot of material. The material would not work satisfactorily, however, with this set of dies, and after several attempts the test was stopped and the rest of the lignite in the hopper was thrown away. .

The next lot of ground lignite, dried to contain 10.8 per cent moisture, was used for test 326. No briquets were made and the material came out of the press in a loose form. The lignite evidently lacked binding properties, a defect that was confirmed by extraction tests made later. Another test (330) was made on a lot of material dried to contain 11.6 per cent moisture, but no briquets were formed. Similar results were obtained on tests 326 and 330. No further tests could be made on this lignite at the time.

The lignite evidently does not contain enough binding material to give briquets on the German press. Without doubt it can be successfully briquetted by adding a binder and using a press made to work with a binder. It is desirable to make further tests of this lignite, first on the laboratory hand press and afterwards on the English machine belonging to the Bureau of Mines.

Briquetting tests.

	Test 324.	Test 325.	Test 326.	Test 330.
Size as shipped..	3″ lump.	3″ lump.	3″ lump.	3″ lump.
Size as used:				
Over ¼ inch...per cent..	1.5	1.5	2.0	1.0
⅟₄ inch to ½ inch...do....	28.0	28.0	30.0	30.0
⅟₁₀ to ⅟₄ inch...do....	30.0	30.0	29.5	28.0
⅟₂₀ inch to ⅟₁₀ inch...do....	20.5	20.5	18.5	19.0
Through ⅟₂₀ inch...do....	20.0	20.0	20.0	22.0
Details of manufacture:				
Machine used..	German.	German.	German.	German.
Briquetting temperature.......................... °F..	93	93	93.6	111
Binder used..	None	None.	None.	None.
Tangent of die angle.................................	⅟₁₆	⅟₁₆	⅟₁₆	⅟₁₆
Steam pressure on drier.......................pounds..	5	5	4	3
Weight of—				
Fuel briquetted..................................do...:	None.	None.	None.	None.
Briquets, average...............................do....				
Heat value per pound:				
Fuel as received..............................B. t. u..	7,738	7,738	6,970	7,385
Briquets..do....				
Moisture in briquet mixture...................per cent..	7.40	7.40	10.80	11.60

GENERAL SUMMARY OF RESULTS.

LIGNITES BRIQUETTED WITHOUT ARTIFICIAL BINDER.

The following were the samples of lignite from which satisfactory briquets were made on the German press without adding a binder:

Field designation.	Situation of mine.	Field designation.	Situation of mine.
Pittsburg No. 8....	Lytle, Medina County, Tex.	Pittsburg No. 13a..	Lehigh, Stark County, N. Dak.
Pittsburg No. 11...	Scranton, Bowman County, N. Dak.	Pittsburg No. 14...	Ione, Amador County, Cal.

a Difficult to briquet.

A. BRIQUETS AT BEGINNING OF WEATHERING TEST

B BRIQUETS AFTER EXPOSURE FOR 9 DAYS.

A. BRIQUETS AFTER EXPOSURE FOR 24 DAYS.

B. BRIQUETS AFTER EXPOSURE FOR 34 DAYS.

A. BRIQUETS AFTER EXPOSURE FOR 46 DAYS.

B. BRIQUETS AFTER EXPOSURE FOR 56 DAYS

A   BRIQUETS AFTER EXPOSURE FOR 66 DAYS.

B.   BRIQUETS AFTER EXPOSURE FOR 96 DAYS.

A BRIQUETS AFTER EXPOSURE FOR 126 DAYS.

B. BRIQUETS AFTER EXPOSURE FOR 166 DAYS.

A. BRIQUETS AFTER EXPOSURE FOR 226 DAYS.

B. BRIQUETS AFTER EXPOSURE FOR 286 DAYS.

Of these samples, that from California was the most easily briquetted; that from Scranton, Bowman County, N. Dak., ranked next; that from Lytle, Medina County, Tex., ranked third; and that from Lehigh Mine, Stark County, N. Dak., ranked fourth.

The fact that no satisfactory briquets were made from Pittsburg Nos. 7, 9, and 15 without a binder does not show that these lignites, with added binder, will not make good briquets, and further tests must be made with such binders as coal-tar pitch, water-gas pitch, sulphite pitch, and some form of starch before a final opinion can be given as to briquetting qualities.

It is worthy of note that each of the States from which the samples came—Texas, North Dakota, and California—furnished at least one sample that made satisfactory briquets without the addition of artificial binder. This fact is encouraging, since it indicates that many American lignites may equal German lignites in briquetting qualities and that some may make better briquets.

VALUE OF EXTRACTION TESTS.

The writer wishes to emphasize the value of an extraction test as a reliable indicator of the briquetting qualities of any lignite. The results of extraction tests of the lignites mentioned in this bulletin bear such close relation to the results of the briquetting tests that the writer feels warranted in stating that a lignite containing $1\frac{1}{2}$ per cent or more matter soluble in carbon bisulphide can probably be briquetted on a press of the German type without the aid of artificial binder.

COST OF BRIQUETS.

The tests described apparently show that the cost of briquetting run-of-mine lignites with a German plant would be from $1.35 to $1.75 per ton, according to the location of the plant.

On the assumptions that the plant costs $56,000; that it is to be located at the mine; is to run 2 shifts of 10 hours each, or 20 hours per day; and is to have a capacity of 50 tons of briquets per day of 20 hours, the costs figure out as follows:

COST OF LIGNITE.

In 1907 the average price per ton of lignite at the mine was:[a] In California, $2.74; in Texas, $1.01; and in North Dakota, $1.61. The average cost of mining coal in the United States [b] may be taken as 90 per cent of the price at the mine; for the three States named the average cost of lignite at the mine would then be: Texas, 90 cents per ton; North Dakota, $1.45; and California, $2.46.

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[a] Parker, E. W., The production of coal in 1907. U. S. Geological Survey, Mineral Resources 1908, pp. 100, 157, and 187.

[b] Finlay, J. R., The cost of mining. 1909, p. 68.

The cost of briquetting may be subdivided as follows:

1. Labor for 2 shifts of 10 hours each:

1 superintendent, at $3 per day_____	$3.00
2 machine operators, at $2.50 per 10 hours_____	5.00
8 laborers, at $2 per 10 hours_____	16.00
Total labor per day for 50 tons of briquets_____	24.00

Labor cost per ton of briquets, 48 cents.

2. Depreciation and maintenance (10 per cent on machinery, 5 per cent on buildings) per day for 50 tons_____ 16.00

Per ton of briquets, 32 cents.

3. Interest on investment (8 per cent per year on $56,000) per day for 50 tons_____ 15.00

Per ton of briquets, 30 cents.

4. Power, 12½ tons lignite per day, or one-fourth ton lignite per ton of briquets made, this item varying for different localities.

The fixed charges (items 2 and 3) thus amount to 62 cents per ton, which, plus the labor charge, 48 cents, equals $1.10 per ton.

In the three States named the items of labor, fixed charges, and power (at mines) would show these totals:

Texas:

Labor and fixed charges_____	$1.10
One-fourth ton lignite for power, at 90 cents per ton_____	.23
Total _____	1.33

North Dakota:

Labor and fixed charges_____	1.10
One-fourth ton lignite for power, at $1.45 per ton_____	.36
Total_____	1.46

California:

Labor and fixed charges_____	1.10
One-fourth ton lignite for power, at $2.46 per ton_____	.62
Total_____	1.72

TOTAL COST.

On the basis of the figures given, the cost per ton of briquets at the mine would be as follows:

Texas:

1.32 tons lignite (33 per cent moisture) for 1 ton briquets_____	$1.18
Briquetting costs_____	1.33
Total_____	2.51

North Dakota:

1.43 tons lignite (40 per cent moisture) for 1 ton briquets_____	2.07
Briquetting costs _____	1.46
Total_____	3.53

California:

1.43 tons lignite (40 per cent moisture) for 1 ton briquets_____ $3. 52

Briquetting costs _____ 1. 72

Total_____ 5. 24

To recapitulate, the cost per ton of briquets, loaded on cars, from a briquet plant at the mine would be, in Texas, $2.51; in North Dakota, $3.53; and in California, $5.24.

It must be borne in mind that these figures are only approximate and are subject to wide changes because of local conditions. They apply to briquetting run-of-mine lignite to improve its heat value and weather-resisting properties rather than to briquetting slack or waste coal. Since the tests have shown that at least some lignites slacked by exposure to the weather can be made into excellent briquets, it may be possible to utilize lignite slack as well as bituminous slack and anthracite screenings for briquetting, the two latter materials having been made into briquets on a commercial scale both in this country and abroad.

Nystrom [a] gives the labor cost of briquetting lignite for plants with one press, 45.4 cents per ton; two presses, 40 cents; three presses, 36.4 cents; four presses, 31 cents; five presses, 27.3 cents; and six presses, 22.3 cents per ton. He further states that "As the wages in Canada are higher [than in Germany] this cost [of labor in a plant with one press] is assumed to be 60 cents per ton." He estimates the depreciation as 5 per cent per year and the maintenance as 3 per cent and the cost of a complete plant with one press and a yearly capacity of 13,000 tons as $75,000. Therefore his estimate of the charges for depreciation and maintenance is 8 per cent of $75,000, or $6,000 per year, 46 cents per ton. Hence the cost of labor and fixed charges, according to his estimate, is about $1.06 per ton, which agrees very closely with the writer's estimate of $1.10 per ton.

In a consular report [b] the cost per long ton of briquetting lignite in Germany is stated as follows:

Cost of manufacture of lignite briquets.

Description.	United States currency.
From lignite taken from the open working under good conditions, with water contents of about 46 per cent:	
In large briquet factories...	$1. 14–$1. 29
In small briquet factories...	1. 19– 1. 38
From lignite taken from the open working, with water contents of more than 46 per cent, in large briquet factories...	1. 38– 1. 62
From lignite taken from the deep working, with water contents up to 46 per cent:	
In large briquet factories...	1. 31– 1. 62
In small briquet factories...	1. 62– 1. 74
From lignite taken from the deep working, with water contents of more than 46 per cent, in large briquet factories...	1. 66– 1. 86

[a] Nystrom, E., Peat and lignite; their manufacture and uses in Europe: Bulletin of Canada Department of Mines, Mines Branch, 1908, p. 147.

[b] Special Consular Reports, No. 26, 1903, p. 107.

In the case of materials containing from 15 to 18 per cent water, for which a drying process is not necessary, the cost of manufacture is naturally considerably lower.

As the cost of labor is at least 25 per cent higher in the United States than it is in Germany, and as the cost of fuel is higher also, the above figures are too low for American practice, though they are useful for comparison.

Robert Schorr,[a] referring to the German lignite industry, states:

The raw brown coal costs from 22 to 31 cents per metric ton (2,204 pounds) at the works. The fixed charges, allowing 7 per cent for depreciation and 5 per cent for interest upon the total investment, amounts to about $1.30 per metric ton of briquets. The wholesale price f. o. b. works ranges from $16 to $23 per carload of 10 tons. The labor item rarely exceeds 24 cents per metric ton (2,204 pounds) in small (one or two press) installations. All other manufacturing items, exclusive of fuel and fixed charges, are fully covered by from 8 to 11 cents per ton. In view of the relatively small output of these expensive presses, and in view also of the elaborate character of German briquetting works, the fixed charges (depreciation and interest) are high. The largest brown-coal company owns 20 briquetting plants with 52 presses. There are a number of other concerns operating from 8 to 42 presses. Only a few factories employ less than 4 machines.

ADVANTAGES OF BRIQUETS COMPARED WITH RAW LIGNITE.

HEATING VALUE.

The following table shows how the heating value of lignite is increased by the removal of moisture during briquetting:

Improvement of heat value by briquetting.

Source.	Field designation.	Moisture.			Heat value, per pound.		
		In raw lignite.	In briquets.	Removed.	Raw lignite.	Briquets.	Increase.
		Per cent.	*Per cent.*	*Per cent.*	*B. t. u.*	*B. t. u.*	*Per cent.*
Texas.................	Pittsburg No. 8...	33.0	9.0	24.0	6,840	9,336	36.5
North Dakota.........	Pittsburg No. 11..	40.0	12.0	28.0	6,241	9,354	50.0
Do...............	Pittsburg No. 13..	42.0	10.0	32.0	6,079	9,355	54.0
California............	Pittsburg No. 14..	40.0	10.0	30.0	6,080	9,264	52.4

Of the four samples of raw lignite named in the table, the three containing about 40 per cent of moisture had a fuel value of 6,079 to 6,241 B. t. u., while the Texas lignite, with a moisture content of 33 per cent, had a fuel value of 6,840 B. t. u. The percentage of moisture removed in the process of briquetting ranged from 24 to 32 per cent, and the heat value of the briquets was 36.5 to 54 per cent higher than that of the raw lignites.

Excessive moisture in fuel not only causes a waste of useful heat during combustion, because the moisture is vaporized and the vapor

[a] Schorr, Robert, Lignite briquetting in Germany; Eng. and Min. Jour., vol. 85, 1908, pp. 460-461.

superheated, but also is a source of expense to the consumer, who pays freight charges on useless water. For both these reasons lignite briquets have the advantage over raw lignite. In the case of one of the North Dakota lignites the removal of 32 per cent of moisture during briquetting permits a decided lessening of the cost of supplying a consumer with a given number of heat units. The advantage of the briquets in this respect is of especial importance when transportation to a distant market is involved. If the briquets possessed no other advantage over raw lignite than their higher heat value, they would be worth 50 per cent more than the raw fuel. The table shows that the heat value of the briquets was about 9,300 B. t. u., although the lignites came from three States and their fuel values varied considerably.

RESISTANCE TO WEATHERING.

The results of the weathering tests indicate that the lignite briquets resist weathering much better than the raw fuel. Some samples of briquets after exposure to autumn and winter weather for four months were in nearly as good condition as at first. Samples stored under cover did not show any signs of deterioration after six months, although the raw lignite stored under the same conditions turned to slack in two months.

RESISTANCE TO HANDLING.

The briquets bear handling better than the raw lignite. Their superiority is, of course, more striking after the lignite and the briquets made from it have been stored for several weeks.

EFFICIENCY AS FUEL.

Preliminary results of producer gas and steaming tests indicate that as gas-producer fuel the briquets were 43 per cent more efficient, and as boiler fuel were 14.5 per cent more efficient than the raw lignite.

LIGNITE-BRIQUET MANUFACTURE IN GERMANY.

The following description of lignite briquet manufacture in Germany,[a] though written several years ago, is reprinted here for the information it gives.

It has been repeatedly stated that the outward cleanliness of Berlin and other German cities is principally due to the general consumption of brown-coal briquets for household and steam fuel; further, that they are made from ordinary German lignite without the use of tar or other artificial binder; that they are compact to store, clean to handle, easy to kindle, burn with a clear,

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[a] From Briquets as fuel in foreign countries; Special Consular Reports, No. 26, 1903, p. 93.

strong flame, are cheaper than good bituminous coal, and are made practically smokeless. Lignite varies in its value and adaptability for briquetting purposes according to its geologic age, hardness, and the percentage of water contained. A lignite with less than 30 per cent of water is very difficult to work by the usual processes, and it is for this reason that Austria-Hungary, which has an abundance of very old and hard brown coal that contains from 26 to 28 per cent of moisture, has practically no supply of briquets from that source. German lignite, on the other hand, is of much more recent formation; it contains from 46 to 52 per cent of water, and is usually so soft that it can be cut with a spade. Many lignite beds in this country are filled with logs and pieces of wood, so well preserved in the matrix of partially carbonized material that they burn readily and form a cheap and abundant fuel for steam and other heating at the briquet factories. The part played by the water contained in lignite forms the key to the whole economic briquetting process. The crude brown coal is brought from the mine, crushed and pulverized, and then run through a large revolving tubular cylinder, heated by exhaust steam from the driving engine, and hung on an inclined plane so that the powdered material runs downward through the tubes by gravity and is carried into the machine press that stamps it into briquets. During this passage through the cylinder it is dried and heated until there remains the right proportion of moisture, combined with the proper temperature to develop the latent bitumen in the lignite and make the powdered mass plastic and easy to mold under heavy pressure between heated iron jaws into a hard, clean briquet, with a glistening surface and sufficient firmness of structure to stand weather, transportation, and other contingencies. To do this perfectly and economically, the natural lignite should contain, as it comes from the mine, approximately enough water so that heating to the proper temperature for pressing will evaporate out just sufficient water to leave it at the proper degree of moisture. The ideal proportion is about 45 per cent of water, so that German lignite contains rather too much, while Austrian contains much too little, though this latter difficulty has lately been partially overcome by steaming. The important question to be now decided is how American lignite will fulfill these requirements.

During the past six weeks samples of lignite from near Bismarck, N. Dak., and from Troy, Ala., have been received at this consulate, turned over to the syndicate mentioned in the last report, and molded experimentally into briquets with entire success. The Dakota lignite is old and hard, contains 38 per cent of water, but crushes and pulverizes easily, and forms without binder briquets of firm structure, which burn readily, are practically smokeless, and leave only 4 per cent of ash, while the best German brown-coal briquets yield from 9 to 12 per cent of inorganic residue. The percentage of water contained is rather low, but by adapting the heating-drying process to that proportion of moisture this obstacle, such as it is, can be easily met, and the reduced task of evaporation will be an economy in the general process.

The Alabama lignite, on the other hand, is an ideal material, and from the one sample submitted is conceded here to be even superior to the standard brown coals of Germany. It contains the direct percentage of moisture, crushes easily, and molds readily into firm, shining, black briquets, so clean that, as one of the experts at Magdeburg said, " They might be used for paper weights."

The importance of these simple demonstrations will be inferred from the fact that, according to a recent State geological report, there are 55,000 square miles of lignite beds in the Dakotas and Montana, all near the surface of the ground, and ranging in thickness from 20 to 80 feet. The extent of the lignite deposits in the Gulf States is perhaps less exactly known, but they certainly cover a large area. There is also lignite in Missouri, Iowa, and several other Western States

and Territories, and it is from all those hitherto practically neglected deposits that an inexhaustible future supply of smokeless domestic fuel will be derived.

It will therefore be of interest to state concisely what constitutes a first-class, up-to-date lignite-briquet factory in Germany, where the industry has reached, after many years' experience, its highest development. A typical example is the factory at Lauchhammer, about 80 miles south of Berlin, on the direct line to Dresden. This establishment, which is of the latest and most approved construction, has eight presses, with the necessary pulverizing, heating, and drying plant, run by electric motors, with current generated by steam evaporated with wood from the mines, the whole under handsome, substantial buildings of brick, stone, and iron, and cost, with tracks, switches, and full equipment for handling raw material and loading the briquets into cars, $371,000, of which $178,500 was paid for machinery. Each press weighs 32 metric tons and stamps out 100 to 200 briquets per minute, or 70 tons in a double-turn day's work of 20 hours. The heating and drying apparatus for each press weighs 18 tons. The power required for each press and drier is 125 horsepower, and both the driers and jaws of the press, between which the briquets are squeezed at enormous pressure, are heated by exhaust steam from the Corliss engine in the power house, the whole supply for the eight machines being equivalent to about 150 horsepower.

Thus equipped the plant at Lauchhammer turns out from 500 to 600 tons of briquets per day, which sell on cars at the factory for from 7 to 9 marks ($1.66 to $2.14), according to season and market, with an average of 8 marks ($1.90) per 1,000 kilograms, or metric ton of 2,204 pounds. Profits depend on the usual varying conditions, location, management, demands, etc., but it is common to read in the Berlin papers official notices announcing dividends of brown-coal briquet companies ranging from 15 to 20 per cent of their capital.

SULPHITE PITCH AS A BINDER.

GENERAL STATEMENT.

In the development of the briquetting industry many patents have been obtained for binding materials, but only a few binders have been found practicable for commercial use. Among these may be mentioned coal tar, coal-tar pitch, water-gas pitch, and asphalt pitch.

A new binding material called "sulphite liquor" also has been suggested for briquetting, but more recently a product called "sulphite pitch," obtained from this sulphite liquor, has attracted considerable attention and apparently possesses valuable properties as a binder. Hence a brief description of this new material is here given.

SULPHITE LIQUOR.

In the sulphite process of preparing pulp for paper making the wood is boiled under pressure with sulphurous acid, or, more commonly, with acid sulphite of calcium and magnesium. The action of sulphurous acid under pressure and at a high temperature upon the lignin and other incrusting matters of the wood fiber is probably a hydrolysis; that is, the complex molecules of the lignin, etc., are broken down and the resulting products, largely organic acids and aldehydes, become soluble in the liquor.

The waste liquors are light brown in color and contain much matter extracted from the wood. Until recently they had no commercial value and their proper disposal was often a serious matter; they polluted streams into which they were emptied, and under certain conditions killed the fish in these streams. It has been suggested they may furnish materials for making oxalic or pyroligneous acids, or alcohol, and investigations have been carried on to devise methods of utilizing them.

SULPHITE PITCH.

Several patents have been obtained in this country and abroad for converting the waste liquors into fertilizers, adhesive material, or other commercial products, but the most promising way of utilizing them at present seems to be by making a concentrated product known as "sulphite liquor," or a solid form known as "sulphite pitch" or "cell pitch" (selpech).

The method of preparing sulphite liquor or cell pitch from the waste lyes, according to W. Sembritski, manager of the Walsum Paper Mills, on the Rhine, is as described below:

At the Walsum factory the evaporation of waste sulphite liquors to a solid pitch, which is used for briquetting blast-furnace dust, promises to develop into a profitable industry. The liquors have a specific gravity of 1.05 and an acidity, calculated as sulphur dioxide, of 0.32 per cent. The thick sirup, density 35° B., from the evaporators 0.32 per cent. The thick sirup, density 35° B., from the evaporators has the following composition: Water, 28.88 per cent; insoluble matter, 13.96 per cent; extract, 57.16 per cent; tanning matters, 22.96 per cent; nontannins, 34.24 per cent. The solid cell pitch contains: Water, 13.76 per cent; soluble extract, 86.60; tanning matters, 31.84 per cent; nontannins, 54.76 per cent. The nontannins of the sirup consist of organic matter, 24.76 per cent; mineral matter, 9.44 per cent. The nontannins of the cell pitch consist of organic matter, 36.08 per cent; mineral matter, 18.68 per cent.

If the evaporators are made of iron, it is necessary to neutralize the acidity of the liquor with lime before concentration, and the incrustation of the tubes with calcium compounds is somewhat troublesome. If copper evaporators are used, the liquors may be concentrated in their acid state. If the concentrated liquor is to be used for briquetting flue dust, the author thinks that neutralization with lime is essential to the proper working of the briquets in the blast furnace. If, on the other hand, the concentrated liquors are intended for tanning purposes, neutralization is a drawback, as the calcium compounds make the leather brittle.

The success of the Walsum experiments is attributed in large part to the sextuple-effect Kestner evaporator used. Each effect has a heating surface of 55 square meters; the first vessel is heated with steam at 3 to 4 atmospheres and the boiling point in the last effect is 50° C. The liquor requires about three hours to reach a concentration of 35° B. The sirup is converted into solid pitch by two steam-heated drums which dip below its surface. The first drum concentrates the sirup from 35° B. to 60° B.; the second converts it into a solid film, which is removed with a scraper. Ten kilograms of waste lye yield 1 kilogram of dry substance. The fuel consumption is reckoned at 1 ton of coal per ton of pitch. It is stated that a selling price of $9.50 a ton would show a good profit.

The pitch has the appearance of black opaque resin, but is quite soluble in water. It is used as a binder for fuel and ore briquets. By its use the dust from blast furnaces, containing 40 per cent of iron and hitherto a waste product, has been formed into briquets for resmelting. It has also been used as a dressing for coarse canvas, etc. Large quantities of the sulphite liquor, having a density of about 35° B., are shipped from Germany to England in iron drums. The

liquor is used in England as a binder for the sand cores and molds used in casting, and is sold there at $12.50 a ton.

SULPHITE PITCH IN GERMANY.

In a report, made in 1909, George E. Eager, United States consul at Barmen, Germany,[a] discussed the merits of sulphite pitch in some detail. He stated that sulphite pitch possesses many qualities which make it an excellent binding agent. It is intensely glutinous and its binding power is high. According to Mr. Eager, in briquetting bituminous coal from 7 to 10 per cent of coal tar is needed to give briquets of the proper firmness, but the same results can be obtained by the use of 5 per cent of sulphite pitch and some kinds of coal or ore that can be briquetted by using only 2 to 3 per cent of it.

Mr. Eager further says that sulphite pitch burns without smoke or odor and is an ideal fuel for the household, as well as for industrial purposes. The use of briquets made with this sulphite pitch will help solve the smoke question in cities. Coke briquets made with this new binder have been tried in blast furnaces and on torpedo boats with promising results. Ocean liners, war ships, railway engines, and factories could all use this fuel to advantage and not only economize in the amount of fuel necessary, but relieve cities from the smoke nuisance.

Sulphite pitch, says Mr. Eager, does not soften under heat and burns at a high temperature. It can be ground to any consistency or can be produced directly in any form of powder; it can be had in every country where there are cellulose mills, and it is very cheap. Anthracite briquets for household use, manufactured with sulphite pitch, burn without smoke or odor; therefore, they are not only an excellent substitute for the anthracite nuts, but are even superior to them.

Regarding other uses of sulphite pitch and its composition, the report states:

Recent trials to briquet coke gravel and dross, the remainder of coke (hitherto useless), with tar pitch have proved failures, but the situation changed immediately as soon as sulphite pitch 'was used as the binding agent, and the results show a briquet that can be considered a perfect substitute for coke. Practical trials of these briquets in both blast and cupola furnaces have shown that the briquets do not fall to pieces under the highest temperature, but burn while gradually shrinking. On account of their consistence they enter deeply into the melting zone of the furnace, thereby naturally contributing materially to the melting effect. Fine ore, bog-iron ore, brown ore, manganese ore, oxide, furnace cadmia (iron dust from blast furnaces), and other ores can all be briquetted by the use of sulphite pitch and successfully melted in the furnace. All trials of briquetting the above materials with coal-tar pitch have failed, because the binding agent burned away at a lower temperature, leaving the ma-

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terial in dust as before. With sulphite pitch it is possible to briquet furnace cadmia so that it can be melted in a blast furnace. This alone means a great saving to the iron industry.

In general, sulphite pitch consists of the following substances: Fixed carbon, 25 to 35 per cent; volatile matter, 50 to 60 per cent; ash, 8 to 12 per cent; and water, 10 to 15 per cent.

The latest chemical tests have proved that the percentage of ash can be materially reduced. Through the origin of sulphite pitch its ashes contain sulphur up to 20 per cent, or 2.5 per cent of the sulphite pitch. The sulphur, however, is tied up to iron and lime, which latter substances are always present in abundance, so that the sulphur remains in the ashes and can not do any damage. It is true that sulphite pitch can be dissolved in water, and that briquets made from it are not waterproof; but this is of no great importance as in most cases a waterproof briquet is not needed. The sulphite-pitch briquet is, however, more waterproof than the lignite briquet, the making of which has become a flourishing industry. The sulphite briquet is not hygroscopic, and can be made absolutely waterproof, if it is necessary, by a simple special treatment.

The production of sulphite pitch, as well as its use in the process of briquetting, call for special processes and machinery which have taken years of expensive experiment to successfully develop, and both the material and its use for briquetting are patented in all the principal countries.

It is not supposed that sulphite pitch will in any way interfere with coal-tar pitch in its use for briquetting soft bituminous coals, but the superiority of sulphite as a binding agent, making possible the briquetting of harder coals and cokes, also iron dust and other ores, opens up a new and very important industry.

THE POLLACSEK BRIQUETTING PROCESS.

Richard Moldenke, consulting engineer on coking practice, Bureau of Mines, furnishes the following information about the Pollacsek briquetting process:

The Pollacsek briquetting process which employs the waste liquor of the sulphite paper-making process as the binder has been adopted by the Hungarian Government for its collieries, and that Government has erected the machinery for the first plant.

It is estimated that a plant producing 10 tons daily will cost about $5,000, and that the cost of operation in the United States will not exceed 60 cents a ton, and may be as low as 40 cents in favored places.

Size of the coal.—Fine coal or slack is used, pieces above a quarter of an inch being crushed. Such crushing is necessary because any large pieces of coal would be shattered in the molds of the press, and, since there would be no binder between the shattered fragments, the briquets would not be strong enough to stand transportation.

The binder.—The inventor has a process in which the waste liquor of the pulp mills may be reduced to a dry powder for convenience in

transportation or evaporated to a sirup. Unquestionably the inventor must first neutralize the free acid and separate it by precipitation. In the United States this removal of free acid is, and has been for several years, accomplished in a commercial way by the use of lime. The evaporated sulphite liquor has a sirupy consistency and considering its price and efficiency is the best core binder for foundry use known to-day.

It is probable that about the same method of removing free acid is used in the Pollacsek process; but the evaporation is completed to make the weight of the product, for cheapness of transportation, as small as possible. In view of the fact that in making fuel briquets only 3 to 5 per cent of this binder is used, its cost per ton of coal briquetted is small. Another point in favor of the process is that by utilizing the waste liquor, which is given away by the mills, it helps protect streams from pollution and merits consideration for this reason alone.

The process.—If the binder is a sirup, it is diluted suitably; if solid pitch, it is dissolved in the proper quantity of water. The fine coal and the binder are then mixed by a machine. From the mixer the briquet material passes into a rotary drying kiln, where it is heated and partly dried. The success of the process depends upon maintaining the right temperature in this kiln, for the product goes directly from the kiln to the briquetting press. If the temperature varies only 10° F. either way from the standard the briquets are not hard and strong enough to stand transportation, but come out of the press uncompacted or fall to pieces. Evidently the adjustment of temperature must be precise.

If the kiln dries the material enough and the temperature in the kiln is kept at the right point, the coal will stick together when pressed, but will not adhere to the molds.

Dust from the rotating cylinder, moisture, etc., are drawn off by a fan. The dust is separated and returned to the mixing machine.

A belt conveyer takes the briquets from the press through a drying oven. If they are not to be waterproofed the briquets go directly to the cars for shipment. If they are to be waterproofed another belt takes the briquets from the drying oven, passes them through an emulsion of bitumen and water and again through a drying oven, and delivers them to the cars.

The actual briquetting process, with its mixing and drying, requires the labor of only a few men. One man gives his time to the drying kiln and the mixer, while another looks after the briquetting machine and keeps track of the briquets until they go into a car. The only other labor required is in connection with bringing in the coal and taking away the cars.

Since little labor is needed and the cost of binder is small, claims of great cheapness are made for the process. The fact that information was refused pending the taking out of patents may indicate that there is little about the process to patent. The secrets of the process are the proper mixing of the coal and binder, the use of a certain kiln temperature, and the control of this temperature, and, finally, the weatherproofing of the briquets.

The briquets made by the Pollacsek process are excellent. They are hard, stand rough handling, and are sufficiently weatherproof for every purpose. Consequently it is not strange that the Hungarian Government has selected this process for use at the Government collieries, since it turns out a good product and removes a source of stream pollution.

A combination of companies making wood pulp and those mining coals that yield culm or slack might find it advantageous to look into the process as a means of solving two interesting problems, the disposal of the waste sulphite liquors and the utilization of waste coal.

The briquetting section of the Bureau of Mines is making laboratory tests with this sulphite pitch, the results of which will be published in a future bulletin.

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INVESTIGATIONS OF EXPLOSIVES USED IN COAL MINES

BY

CLARENCE HALL, W. O. SNELLING, AND S. P. HOWELL

WITH A CHAPTER ON THE NATURAL GAS USED AT PITTSBURGH BY

G. A. BURRELL

AND AN INTRODUCTION BY

CHARLES E. MUNROE

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INVESTIGATIONS OF EXPLOSIVES USED IN COAL MINES.

By Clarence Hall, W. O. Snelling, and S. P. Howell.

INTRODUCTION.

By Charles E. Munroe.

The explosives used in coal mines not only occasion accidents such as occur in the use of explosives elsewhere, but they frequently cause widespread disasters by igniting explosive mixtures of mine gas and air and of coal dust and air, or both. In addition, the firing of explosives so shakes the walls and roofs of the mines as to cause falls, with their attendant casualities.

Considering the large number of explosives and their wide range in composition and properties, it is obvious that certain of them should prove more suitable for use in coal mines than others. The problem is to determine which explosives are the most suitable for this purpose and the precise conditions under which they may be used with the greatest safety.

Of course this problem could be worked out in actual mining, but experimental investigations when accompanying commercial operations are hazardous and slow. To obtain the information sought, in the speediest and most economical manner, laboratory methods must be resorted to. The adoption of such methods began about 30 years ago with experiments in an iron gallery mounted on wheels, at Zwickau, Germany. This laboratory method of attacking the problem has so commended itself that it has not only been repeated elsewhere in Germany but has at intervals been officially adopted, with many modifications and additions, by the Governments of Belgium, Austria, France, and Great Britain.

Such was the status of coal-mine investigations in Europe when in 1904, an organization in the Geological Survey, which in 1907 became the technologic branch, was created to investigate the mineral-fuel resources of this country. At that time no division of the National Government had official cognizance of conditions existing in our mines, but through its system of collecting fuels for tests the technologic branch was forced to recognize that coal-mine accidents are a factor that must be reckoned with in determining the extent and availability of our mineral-fuel resources. This became so

apparent, and it was so obviously a function of this branch to make a systematic research as to the cause and prevention of such accidents, that in July, 1907, experts were appointed especially to deal with this problem. As a result, not only was Bulletin 333, on Coal-Mine Accidents: Their Causes and Prevention, prepared and published, but through personal inspection of foreign testing stations, and a study of their reports and the critiques of their methods and operations, definite plans for the establishment of such a testing station in this country were formulated.

In the latter part of 1907, four grave disasters occurred in close succession consequent on explosions in the Monongah mines in West Virginia, where 368 men were killed, the Darr mine in Pennsylvania, where 160 were killed, the Naomi mine in Pennsylvania, where 34 were killed, and the Yolande mine in Alabama, where 61 were killed. These frightful disasters so quickened the public conscience, and so plainly demonstrated that both humanitarian and economic needs demanded that steps be taken to prevent the recurrence of such accidents, that in 1908 Congress made a special appropriation for an investigation as to the "causes of mine explosions." A similar appropriation was made in the following year. By act of May 16, 1910, the Bureau of Mines was created "to make diligent investigation of the methods of mining, especially in relation to the safety of miners, the use of explosives, the prevention of accidents," and other matters relating to mining. Therefore, these investigations are at present conducted in obedience to an organic act instead of being dependent solely upon special appropriations.

The first appropriation became available July 1, 1908. Through the courtesy of the War Department a portion of the grounds and buildings of the arsenal at Pittsburgh was granted for the use of the technologic branch of the United States Geological Survey. Work was immediately begun in procuring and erecting the necessary instruments and appliances for carrying out the desired tests and investigations and in adapting the existing buildings or in erecting new structures to contain the apparatus. The Pittsburgh testing station was officially opened and regular work was commenced on December 3, 1908, the apparatus and appliances having been tested, the force drilled in their use, and the equipment and methods inspected and passed upon by foreign experts.

A special feature of the station is the appliances for investigating and testing explosives to determine their suitability for use in coal mines. The apparatus employed, the methods of using it, and the results obtained in testing 23 different explosives are set forth in this bulletin. An important part of the plant is a well-equipped chemical laboratory where the explosives are carefully analyzed and studied to ascertain their chemical properties. Here the gas-air

mixtures into which the explosives are fired and the coal dust used in this connection, the igniters or detonators employed, and the products of explosion are analyzed. The extent to which this chemical work is carried on is shown by the report on the tests of four foreign explosives, also given in this bulletin.

At the outset it was recognized that in order to correlate the behavior of explosives, a standard of reference must be selected. Modern practice indicated that this must be a "detonating" rather than a "burning" explosive, and after due consideration and inquiry, a dynamite of the following composition was selected: Nitroglycerin, 40 per cent; sodium nitrate, 44 per cent; wood pulp, 15 per cent; calcium carbonate, 1 per cent. It should be definitely understood that this standard was adopted solely for the purpose of comparing and standardizing the characteristics developed by an explosive when it is fired, and that this standard is not an ideal explosive for use in coal mines. On the contrary, it is quite unsuitable for such a purpose. It was selected because it is well known through long use, is comparatively simple in its composition, and is easy to reproduce. Having standardized by its means the characteristics of an explosive, determination can then be made of the relative fitness of the explosive for use in coal mines by subjecting it to various tests described in this bulletin. These tests are based on the practices and are confirmed by experiences at foreign testing stations.

The last-mentioned terms are intentionally used in the plural for when the investigation of European testing stations referred to above was made in 1907 the methods and practices pursued at these stations were found to vary widely. The subsequent more searching inquiry made on behalf of the technologic branch by Axel Larsen disclosed the fact that not only did the foreign testing galleries differ in form, dimensions, material, and location (on or beneath the surface of the earth) but that the character of the explosive mixtures used within the galleries also differed. Likewise various methods were used in proving the characteristics and composition of these mixtures, and in firing the explosives. Moreover it was found that the requirements as regards other tests than gallery tests were not identical. But it was shown by statistical investigations that in all countries where testing stations were maintained the loss of life in coal mining was diminished, though, because of the many factors which enter into the problem, it was not possible to show the specific effects of the testing of the explosives or of the regulations governing their selection and use.

In determining the character of the tests to be applied at the Pittsburgh station account was taken of these differences, and it was decided that the details of the tests must be worked out to satisfy the conditions imposed by the particular compositions of the gas and

coal dust available for use. This was done, and under date of January 8, 1909, the Director of the Geological Survey issued a notice to manufacturers of explosives in the United States to the effect that official tests of such explosives as the manufacturers might desire to have tested as to their permissibility for use in coal mines, would be made at the Pittsburgh station. This notice described the test requirements to which explosives would be subjected, and set forth the conditions under which the explosives would be received. A copy of the test requirements is appended to this bulletin. Inspection of the requirements shows that a permissible explosive is not only one that has passed the prescribed tests, but is such only when it has the composition and characteristics of the sample submitted for test, and then only when it is used under the prescribed requirements as to quantity used, condition (that is, not frozen), method of confinement, and device for firing it.

The United States Government does not compel nor prevent the use of any explosive or prescribe the conditions of use. It only advises the public as to the character of explosives and as to the manner in which they should be used. It is, therefore, gratifying to state that the manufacturers of explosives in this country cooperated so promptly and so cordially in the endeavor to protect the lives and persons of those engaged in mining coal that by January 1, 1910, there had been received 51 applications for the testing of 134 different explosives. During that year 64 of the explosives submitted were tested and 36 of these passed the tests required to place them on the list of permissible explosives.

The data obtained in testing the dynamite chosen as a standard, the black blasting powder, which up to the founding of the Pittsburgh testing station was used almost universally as the explosive agent in our coal mines, and the first 17 explosives which passed the prescribed tests and were placed on the permissible list, are recorded in this bulletin, so that the results upon which the decision was based in each case may become commonly known and may be freely exposed to criticism by those competent to pass upon these matters. The results of the tests of four foreign explosives which have been tested at the European stations are also given in order that data may be supplied through which to correlate or differentiate the conditions, methods, and requirements of the different governmental stations.

To promote the general interest in this inquiry and to extend among the consumers of explosives such a knowledge of them as will lead to their more intelligent and efficient use, a chapter has been devoted to the consideration of the nature and properties of explosives. Likewise, a chapter on thermochemistry has been added to assist the manufacturer in compounding his materials so as to make an explosive which will satisfy the special requirements of coal mining.

CHAPTER I.

NATURE AND COMPOSITION OF EXPLOSIVES.

By WALTER O. SNELLING.

CHEMICAL NATURE OF EXPLOSIVE MATERIALS.

When combustible matter of any kind is ignited in the presence of air, certain manifestations occur, which are styled "combustion," and it is said that the material "burns." The combustible material unites chemically with the oxygen of the air, and this union gives rise to heat and other phenomena which always accompany active combustion.

Nearly all the explosives in use at present depend for their action on the chemical union of combustible material with oxygen, and it is mainly in the extreme rapidity of the combustion, due to the closeness with which the particles of combustible matter are associated with oxygen in explosive bodies, that the action of explosives differs from the burning of ordinary inflammable substances. Gunpowder, for example, consists of a mixture of potassium nitrate, sulphur, and charcoal. Sulphur and charcoal are combustible, and potassium nitrate contains a large proportion of oxygen which is so held that under suitable conditions it is readily given up. When a grain of gunpowder is heated to its ignition temperature, the potassium nitrate gives up part of its oxygen under the influence of the heat, and the sulphur and charcoal at once burn vigorously in the oxygen thus evolved. This burning of the sulphur and charcoal produces much heat, which raises the temperature of surrounding particles of powder to the ignition temperature, and causes them to burn. As the particles of potassium nitrate are intimately associated with the particles of sulphur and charcoal, each particle of sulphur and charcoal is in contact with a source of oxygen, and therefore the burning of gunpowder is extremely rapid.

Gases are formed by the burning of the charcoal and sulphur, and these gases are highly heated and expanded by the large quantity of heat produced. The gases in their expanded condition have a volume several hundred times as great as the powder from which they were formed, and it is to the sudden formation of these large volumes of highly-heated gases that gunpowder and other explosives owe their strength and their power of doing work.

The volume of gas produced and the heat liberated by the combustion of different materials vary greatly. Likewise there are many

materials that do not produce gases when they burn. When powdered aluminum, for example, is mixed with an oxidizing agent and ignited, very great heat is produced, but no gases are formed because the substance produced by the union of aluminum and oxygen is a solid that is not volatile at ordinary temperatures. When charcoal (which consists principally of carbon) is burned, a gas, carbon dioxide, is produced, and this gas tends to occupy a space many hundred times the volume of the carbon from which it was formed. As most explosives owe their power entirely to the expansive action of great volumes of gas set free at the moment of combustion, it can readily be seen why carbon, either in the form of charcoal, or combined with other elements in the form of starch, wood pulp, etc., forms one of the constituents of so many explosives, and why aluminum and similar materials, which yield no gaseous products of combustion, are seldom so used.

Since the rapidity of burning of any material depends in large measure upon the proximity of its combustible components to oxygen, in the manufacture of gunpowder the charcoal, sulphur, and potassium nitrate used are very finely pulverized, well mixed, and pressed together, so that the particles of combustible material will be in close contact with the source of the oxygen required for their combustion. In a few compounds (of which nitroglycerin is a good example) combustible materials and loosely held oxygen exist in the same chemical substance. In such compounds the association of oxygen with combustible materials is much closer than it can be in a mechanical mixture such as gunpowder, and the explosive action of these materials is therefore far more rapid and powerful.

Nitroglycerin is a heavy viscous liquid formed by the action of a mixture of strong nitric and sulphuric acids upon ordinary glycerin. The chemical change that takes place through the action of the mixture of concentrated nitric and sulphuric acids upon glycerin and similar materials is called "nitration." It results in the introduction of weakly held oxygen into the glycerin molecule, this oxygen being directly united to nitrogen, a chemical element for which it has a comparatively weak affinity. Only when the chemical stability of nitroglycerin is disturbed, as by heat or percussion, does the stronger affinity of the oxygen for carbon and hydrogen, which form the combustible constituents of nitroglycerin, cause it to unite with them, and thus to bring about the explosion of the compound. Although it differs chemically from glycerin, nitroglycerin closely resembles unnitrated or ordinary glycerin in appearance, the color and viscosity of the two substances being closely similar.

When nitroglycerin was first used commercially it was ignited by a fuse in the same way that gunpowder is, under these conditions forming an explosive material not much stronger than gun-

powder. Discovery was soon made, however, that if nitroglycerin is exploded by firing a small charge of fulminate of mercury in contact with it, it develops enormously greater force than when simply ignited by means of a fuse. This discovery marked the real beginning of the knowledge and use of high explosives.

It is well known that when a small piece of lead or copper is placed upon an anvil and struck a violent blow with a hammer, it becomes hot, the energy of the blow being transformed into heat, which raises the temperature of the material struck. It is probable that the main reason the explosion of a small charge of fulminate of mercury causes nitroglycerin to explode so violently is because the energy of the blow caused by the explosion of the fulminate is transformed into heat at the point of contact with the nitroglycerin, suddenly raising its temperature much higher than its ignition point. The nitroglycerin in immediate contact with the charge of fulminate is thus exploded, and the shock produced by the explosion of this portion of the nitroglycerin is in a similar manner transformed into heat. This raises the temperature of the surrounding nitroglycerin to a point well above its ignition temperature, and the explosion is thus almost instantly transmitted through the entire mass of nitroglycerin.

Since a shock or blow is transmitted or carried through a body such as nitroglycerin much more rapidly than flame can be transmitted from particle to particle, the explosion of the material is far more rapid and violent when started by the blow from mercury fulminate than when started by simple ignition of the material. The name "detonation" has been given to this form of explosion to distinguish it from the less rapid and violent form of explosion produced by the combustion of such materials as gunpowder, in which transmission of flame takes place from particle to particle of the material. Although the combustion of gunpowder and other explosives of that type is extremely rapid, the detonation of nitroglycerin and similar explosives is so much more rapid that it may be considered to be instantaneous.

DISTINCTION BETWEEN DETONATING AND SLOW-BURNING EXPLOSIVES.

As already noted, explosives owe their effects to the development, at the moment of explosion, of enormous quantities of gas, which tend to occupy a space hundreds of times greater than that which served to contain the explosive before it was fired.

In the case of explosives which detonate, the transformation of the substance into gas at the moment of explosion is practically instantaneous, and accordingly the pressure produced by the gases thus formed is sharp and sudden. In a period of time less than the thousandth of a second, the explosive is transformed by the chemical

reactions taking place into gases which tend to occupy several hundred times the original volume of the explosive. Everyone who has witnessed the firing of charges of detonating explosives is familiar with the shattering and rending effects produced as the result of this instantaneous development of great quantities of gas.

Many explosives which do not detonate produce fully as much gas as detonating explosives do, but because the explosive reactions take place more slowly, the development of the gas is more gradual and the pressure produced by the explosion, instead of being very high and of short duration, is lower and more prolonged.

For certain purposes the shattering effect produced by detonating explosives is of great value. Such explosives find a wide field of usefulness in blasting and tunneling in hard and tough rock, in breaking up old metal castings, and for similar purposes. In like manner, explosives of slower action have advantages over detonating explosives for many kinds of work. In order that an explosive may be a suitable agent to act as a propellant in guns, it is essential that its action should not be too quick. A certain length of time is required to set the projectile in the gun in motion, and if a detonating explosive were used, its rapidity of action would be so great that, before the ball could be set in motion, the pressure produced by the gases formed would burst the gun.

The term "high explosive" is ordinarily applied to explosives whose usual manner of action is by detonation, and the term "low explosive" is applied to those in which the slower form of reaction ordinarily takes place.

These terms have the advantage of convenience, but the fact should not be lost sight of that they do not rigidly classify explosive compounds, since many materials will either detonate or burn quietly, depending upon the manner in which the initial decomposition is brought about and upon the physical state of the explosive. Nitrocellulose, for example (an explosive produced by nitrating ordinary cotton by means of a mixture of nitric and sulphuric acids, and often spoken of as "guncotton"), finds its largest use as a slow-burning or propellent agent in cannon and small arms, the smokeless powder of the United States and several foreign nations consisting essentially of nitrocellulose. As thus used, nitrocellulose is a low explosive, but if it be fired by means of a charge of fulminate of mercury, it detonates, and under these conditions is a high explosive, its strength and action not differing greatly from that of nitroglycerin.

In order to obtain satisfactory results from low explosives, the charge must be confined, but the action of detonating explosives is so rapid that if simply laid upon rock or other material and exploded they exert a strong rending and shattering effect, although it is to be noted that under these conditions the effect is less than when the

explosive is properly confined. When large quantities of gunpowder and similar low explosives are fired, as in the case of an explosion of a magazine, shattering effects similar to those of high explosives are often produced, but in this case it is the effect of the great quantity of explosive that brings about these results, the total quantity of gases produced by the explosion being so great that the innermost portions of the gunpowder are more or less confined by the enormous volumes of gas produced about them.

USE OF NITROGLYCERIN IN EXPLOSIVE MIXTURES.

For a number of years after its discovery nitroglycerin was little used, as its liquid state made it inconvenient for blasting and similar purposes, and its extreme sensitiveness to shock made it dangerous to handle. Later both of these difficulties were overcome by absorbing nitroglycerin in a suitable porous material, and to this mixture the name "dynamite" was given. Infusorial earth (also known as kieselguhr), a substance which, like chalk, is composed almost entirely of shells of microscopic organisms, was found to be best suited as an absorbent for nitroglycerin. It is abundant in many parts of the world, and forms beds of considerable thickness that represent former sea-bottom deposits.

Infusorial earth is able to take up several times its own weight of nitroglycerin, thus producing a pasty or plastic mass having somewhat the consistency of wet sawdust. A mixture of 1 part by weight of infusorial earth with 3 parts of nitroglycerin is called a 75 per cent dynamite, as it contains 75 per cent by weight of nitroglycerin; and, similarly, a mixture of 2 parts by weight of infusorial earth and 3 parts of nitroglycerin is known as 60 per cent dynamite.

The nitroglycerin is simply held mechanically in the infusorial earth, each of the microscopic shells and shell fragments of which that material is composed being covered by a film of nitroglycerin, held by capillary attraction. Infusorial earth has no explosive properties, and accordingly plays no part in the explosive action of dynamite, the strength of the explosive being simply that of the nitroglycerin present, modified and weakened slightly by the presence of the chemically inert absorbent material.

It is evident that additional strength can be given to dynamite if, instead of an inert material like infusorial earth, an active explosive agent be used as the absorbent for the nitroglycerin. Dynamites containing kieselguhr, chalk, or other inert absorbent materials have at the present time been almost entirely replaced by dynamite with an active base consisting usually of a mixture of sodium or potassium nitrate with wood pulp, sawdust, or charcoal. Such a base is practically a low-grade gunpowder.

When dynamite made with an active absorbent mixture is exploded, the detonation of the nitroglycerin fires the gunpowder mixture,

which serves by the heat of its combustion to still further expand
the gases produced by the decomposition of the nitroglycerin. In this
way, as well as by the gases that it produces, the gunpowder mixture
increases the strength of the explosive.

A still more important advantage of the use of an active base in
the preparation of dynamite is the manner in which the force of the
explosive is modified as the result of the presence of the active
absorbent. The explosion of nitroglycerin alone, as has been seen,
is extremely .rapid, and only at the instant of detonation are the
gases produced by its decomposition highly expanded. The ex-
plosive action of gunpowder mixtures is much slower, and in
dynamites having an active base the heat produced by the combus-
tion of the wood pulp in the oxygen set free from the nitrate serves
to keep in an expanded condition the gases formed by the decom-
position of the nitroglycerin. This not only adds to the power of the
explosive, but also modifies its action in such a way as to consider-
ably increase its effectiveness in blasting. The explosion of the
nitroglycerin serves to shatter the rock, and the action of the gun-
powder base in maintaining the gases at a high temperature serves
to give duration to the gas pressure, and thus to add a heaving force
to the blow which is produced by the nitroglycerin alone.

Dynamite is put up in cylindrical cartridges of heavy paraffined
paper. Usually these cartridges are about 8 inches long and 1 or 1¼
inches in diameter, but cartridges varying in diameter from three-
fourths of an inch to 3 inches, and of different lengths to suit special
conditions or the desires of different purchasers, are also made. A
cartridge measuring 8 by 1¼ inches contains about one-half pound of
dynamite.

The composition of two typical dynamites of different strength is
given in the following table:

Composition of two typical dynamites.

Constituents.	45 per cent dynamite.	60 per cent dynamite.
Moisture...............................	1	1
Nitroglycerin..........................	45	60
Sodium nitrate.........................	41	20
Calcium carbonate......................	1	1
Wood pulp..............................	12	18
	100	100

Other constituents besides those mentioned are sometimes used in
dynamite. A part of the nitroglycerin may be replaced by ammo-
nium nitrate or by a nitrated compound. Other combustible
materials are also substituted for wood pulp. All the constituents of
dynamite tend to take up moisture, and most dynamites contain
from 0.5 to 1.5 per cent of moisture, which was present in the original

ingredients or was taken up in the course of manufacture and storage. Calcium carbonate is added to dynamite to neutralize any acidity that might develop in the nitroglycerin, it being found that nitroglycerin sometimes tends to decompose in this way. It is claimed that dynamite containing a substance like calcium carbonate is somewhat safer to store and handle than dynamite not containing such a constituent.

The conditions under which nitroglycerin is present in dynamite serve to protect it in a considerable measure from the influence of shocks and blows, and dynamite is much less sensitive and less liable to accidental explosion than is nitroglycerin alone. It is not dangerous to handle and use if proper care is taken and if it is protected from shocks and blows of great violence and from too high a degree of heat.

PERMISSIBLE EXPLOSIVES.

In explosives for use in the open air, such as, for example, quarrying or railroad excavation, strength and efficiency in removing rock are the qualities that are most important, and usually are the only ones that need consideration in the selection of a suitable explosive. Explosives that are to be used in tunneling must not only possess strength and efficiency but also be of such composition that upon exploding they will not give off large quantities of poisonous or offensive gases. In explosives intended for use in coal mines, a further property is most important. Besides possessing the qualities of strength, efficiency in breaking down coal, and freedom from poisonous explosion products, the explosive should be of such nature as not readily to ignite explosive mixtures of gas or coal dust.

The underlying causes for one explosive being safer than another in the presence of explosive mixtures of gas or coal dust have been investigated during the past few years. The many thousands of lives lost in coal-mine disasters have shown the necessity of such investigations, and have stimulated to a marked extent researches in regard to the preparation of explosives suitable for use in coal mining. It has been found that every known explosive, if fired in a sufficiently large charge, will cause the ignition of an explosive gas mixture, but explosives have been found to differ widely in regard to the amount that can be fired without causing such ignition. Ordinary black blasting powder, for example, will cause the ignition of explosive gas mixtures very readily, as little as 25 grams (somewhat less than an ounce) invariably serving to bring about this result. Certain other explosives, in quantities as great as 1,000 grams (2¼ pounds), after repeated trials, under conditions exactly similar to those used in testing black powder, have invariably failed to cause ignition of the explosive gas mixtures.

In certain European countries where regulation of the manufacture and use of explosives is recognized as a proper means of safeguarding life and protecting users of explosives from dangerous compounds that might be made and sold by persons not possessing sufficient knowledge or technical skill, all explosives intended for use in coal mining are subjected to tests to determine their fitness for such use. Only explosives that can be fired in charges equal to those employed in mining work, without causing the ignition of explosive mixtures of fire damp, are allowed to be used in coal mining. The explosives that pass the required tests for safety in the presence of gas, for keeping qualities, for safety in handling, etc., are called "permitted explosives," and their use is allowed in coal mines under such regulations as are found necessary to insure safety in handling and loading and the employment of proper means of firing.

In the United States, in the absence of a national law covering the use of explosives, authority controlling the use of such materials lies with the legislatures of the several States. Up to the present day the regulations in different States have been far from uniform and in many States have been inadequate. Accurate information in regard to the action of different kinds of explosive materials is necessary for efficient legislation, and such information has been nowhere available. It is to remedy this condition and provide accurate data in regard to explosives, that tests of coal-mining explosives are being made by the Bureau of Mines. These tests serve to show which explosives are safe and which are dangerous for use in coal mining, and to determine such other properties of explosives as are of importance in the safe and efficient use of these materials.

All explosives that satisfactorily pass such tests as show that they can be fired in considerable quantities in explosive gas mixtures without causing ignition, and in addition possess such qualities of stability, etc., as make them reasonably safe to handle and transport, are termed "permissible explosives." Only such explosives are deemed suitable for use in coal mines in which dangerous quantities of fire damp or inflammable coal dust are likely to be met.

Permissible explosives of most varied composition have been prepared, but in all of them the explosive power is due to the reaction of oxygen with combustible elements, such as carbon and hydrogen, the composition of the explosives being such that the temperature resulting from this combustion is not so high, nor so long continued, as with ordinary explosives. An inflammable gas mixture can be ignited either by a very high temperature acting for a short interval of time, or by a lower temperature acting through a longer space of time; but if a low temperature only is produced by the explosive, and this temperature is of very short duration, the ignition

of the explosive gas mixtures is much less likely. Accordingly the problem of making explosives for use in coal mines is seen to be, in its simplest form, the making of an explosive, that, although producing a low temperature of short duration, shall nevertheless produce a sufficient quantity of gases, and at sufficient pressure to perform by their expansion the work for which the explosive is intended. Through scientific studies and experimentation, manufacturers of explosives have found ways of obtaining this result. Nitroglycerin, ammonium nitrate, and other well-known explosive materials are combined with various substances so as to form explosives that, when properly used, so greatly diminish the risk of accidental ignition of fire damp or coal dust that it may be said to be practically eliminated.

CHAPTER II.

THERMOCHEMISTRY OF EXPLOSIVES.

By Walter O. Snelling.

GENERAL THERMOCHEMICAL CONSIDERATIONS.

With all chemical changes there are involved energy changes, and these usually take the form of absorption or evolution of heat. In a few special cases energy in some form other than heat, as electricity, for example, is produced as the result of chemical reactions, but it may be assumed as a general rule that an energy change, usually with the evolution of heat, will be a part of every chemical reaction. It is important to note that the energy changes connected with any particular chemical reaction are definite in quantity, and are quite as susceptible of measurement and exact determination as the chemical products which result from the alterations of the reacting bodies. The study of the heat evolved or absorbed in connection with chemical changes forms the field of thermochemistry. When physical changes occur without any corresponding chemical change, energy changes may also take place, leading to the absorption or evolution of heat. For example, to change liquid water at its boiling point (100° C.) to gaseous water at the same temperature a certain quantity of heat is required. Another example of physical change accompanied by heat transfer is when a solid body, at any temperature, is dissolved in water at the same temperature. In such a case, where no chemical change results from the mixing of the solid and the water, heat is usually absorbed.

It is necessary to have some unit by which heat changes may be measured, and the unit that has been adopted is called the "calorie." By definition a calorie is that quantity of heat which is required to raise the temperature of 1 gram of water 1° C. As the quantity of heat required to raise the temperature of water 1° varies slightly at different temperatures, it is desirable in accurate work to still further define the calorie, and for the calculations that follow the calorie is defined as "that quantity of heat necessary to raise the temperature of 1 gram of pure water 1° C., from the temperature of 15° to that of 16° C."

Some writers have used the unit called the "mean calorie," this being the average quantity of heat required to raise 1 gram of water 1° between the temperature of 0° and 100° C. The unit actually used is one one-hundredth of the quantity of heat required to raise

1 gram of water from 0° to 100° C., this being a value that can be determined experimentally with considerable accuracy. Very careful measurements have shown that the quantity of heat required to raise 1 gram of water from 15° to 16° C. is almost identical with the "mean calorie," and accordingly these values may be considered as interchangeable in all except the most exact work.

A few writers have preferred to use a heat unit larger than that here defined, and have taken as a standard the amount of heat required to raise 1,000 grams of water 1° C. This value is found in a number of books on chemistry, and is termed the kilogram calorie or "large calorie." Considerable confusion has resulted from the use of the same word calorie, to denote two different values, and in consulting tables of thermo-chemical data it is always necessary to notice carefully whether the "large calorie" or the "gram calorie" is taken as the standard. In the figures given in the present paper "calorie" in every case refers to the gram calorie, as above defined.

Every chemical equation expresses a reaction between definite quantities of matter, and the relation between the quantities of the varying substances entering into the reaction may be determined by calculation. As the methods by which such calculations are made, and the significance of the atomic and molecular weights of the combining materials are treated in all textbooks of chemistry, no detailed description need be given here. A typical reaction, such as

$$C + O_2 = CO_2$$
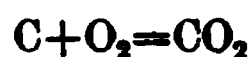
expresses, in addition to the simple information that carbon unites with oxygen to form carbon dioxide, information in regard to the quantities of material that react, and the equation may be read:

One chemical equivalent, or 12 parts by weight, of carbon, unites with two chemical equivalents, or 2×16 parts by weight, of oxygen, to form one chemical equivalent, equal to 44 parts by weight, of carbon dioxide.

The number of parts by weight that each equivalent represents is found by reference to a table of atomic weights. In the calculations that follow, the atomic weights used will be expressed as whole numbers, the variations that many atomic weights show from whole numbers being neglected for the sake of simplicity. It is evident that in a chemical equation the number of "parts by weight" is entirely independent of the nature of the unit of mass taken, so that in the equation represented above it can be assumed that the "12 parts by weight" of carbon refers to 12 ounces, or 12 pounds, or 12 grams, etc., and in each case the relationship expressed by the equation will hold good if the same unit of mass be used for each of the other substances involved in the reaction. In chemical work it is customary to use the gram as the standard of weight, and thermo-

chemical tables in stating the heat of reaction of a substance usually make use of either the gram or the molecular weight of the substance expressed in grams, as the unit of quantity.

Having accepted standards in which the quantity of material entering into a chemical reaction may be stated, and having taken units by which the heat change produced in the reaction can be expressed, it becomes possible to systematically classify all thermochemical data. In the reaction that has already been referred to, in which 12 grams of carbon unite with 32 grams of oxygen to form 44 grams of carbon dioxide, it has been found that 94,300 gram-calories of heat are evolved. This fact may be conveniently expressed as follows:

$$C + O_2 = CO_2 + 94{,}300 \text{ calories}$$
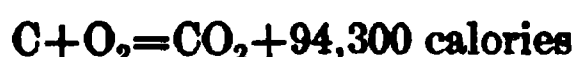
When 12 grams of carbon unite with 16 grams of oxygen to form carbon monoxide, 26,100 calories are evolved, and this fact is expressed in a similar way:

$$C + O = CO + 26{,}100 \text{ calories}$$

Carbon is an element that exists in several modifications, and accordingly it becomes necessary to state which variety of carbon has been used in any chemical equation, since the heat changes differ with different modifications. Carbon in the form of graphite produces a smaller quantity of heat when burned to form carbon dioxide than does carbon in the amorphous condition, such as charcoal.

Berthelot, to whose work we owe much of our present knowledge of thermochemistry, adopted crystallized carbon (diamond) as the standard form to which all thermochemical data in regard to carbon should be referred. As use is made of many of the values determined by Berthelot in all work with explosives, it is desirable to refer all thermochemical data regarding carbon to the same standard that he used, although for many reasons it would have been better if Berthelot had reduced all his results to amorphous rather than to crystallized carbon. Thermochemical values based upon the use of amorphous carbon may be recalculated in terms of crystallized carbon, since the thermal change involved in the transformation of amorphous to crystallized carbon has been calculated. This value is:

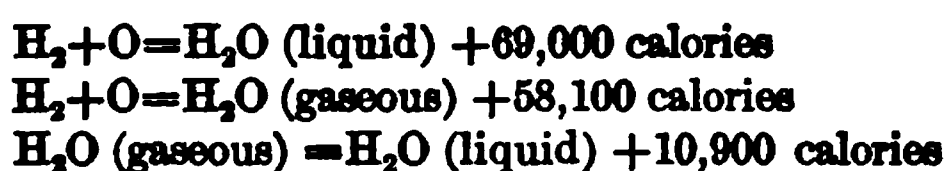$$C \text{ (amorphous)} = C \text{ (crystallized)} + 3{,}350 \text{ calories}$$

Accordingly, in any reaction 12 grams of amorphous carbon will evolve 3,350 calories more than will 12 grams of crystallized carbon, and this same relation will hold good in regard to any energy changes in which carbon is involved.

In expressing thermochemical changes it has been found desirable to assume that the thermal value of all elements is zero and to estimate all heat transfers upon this assumption. It has already been seen that when carbon unites with oxygen to form carbon dioxide, 94,300 calories are evolved. Since the thermal values of carbon (crystallized)

and of oxygen are taken as zero, the 94,300 calories evolved in this union of carbon and oxygen represents the fundamental quantity of heat in regard to 1 gram-molecule of carbon dioxide produced. Thus, the amount of heat produced when any material is formed from its elements is called its "heat of formation," and represents the energy bound in the compound by virtue of the affinity of its elementary constituents.

The heat of formation of a material varies with the physical condition in which it exists. Thus, the heat of formation of liquid water is 69,000 calories, while that of gaseous water is 58,100 calories, and the difference between these two values represents the thermal change involved in this transformation of liquid water to gaseous water. The three equations may be thus represented:

$$H_2 + O = H_2O \text{ (liquid)} \ +69,000 \text{ calories}$$
$$H_2 + O = H_2O \text{ (gaseous)} \ +58,100 \text{ calories}$$
$$H_2O \text{ (gaseous)} = H_2O \text{ (liquid)} \ +10,900 \text{ calories}$$

The quantity of heat produced in any chemical reaction has been found to vary according to the temperature at which the reaction occurs. But, if the substances entering the reaction and the products resulting from the reaction are brought to the same temperature, so that the initial and final states of the system are the same, the equation is unaffected by the temperature at which the reaction takes place. In expressing all thermal values it is customary, except where a note is made to the contrary, to take 0° C. as the initial and final temperature of the reacting substances.

It is one of the laws of thermochemistry that the quantity of heat liberated or absorbed by any set of chemical changes depends solely upon the initial and final states of the system, and is the same whatever the nature of the intermediate steps. Noting, therefore, that all thermochemical equations indicate the amount of heat liberated or absorbed in the reaction of the original substances, at 0° C., with the formation of the resulting products, also brought to 0° C., it will be seen that the thermal value which the equation gives represents solely the energy changes involved in the transformation of the original to the final substances, and is not in any way connected with the reactions by which these changes have been brought about. Because of this fact it is possible to make calculations in regard to the heat produced by explosives, although the changes which occur in many of the reactions are very complicated and are only imperfectly known.

THERMOCHEMISTRY OF CARBON DIOXIDE AND CARBON MONOXIDE.

Carbon, either as the element or combined with other elements to form cellulose, starch, or similar compounds, is the principal combustible constituent used in the preparation of commercial explosives.

In gunpowder, carbon is used in the form of charcoal. Pure charcoal is amorphous carbon and ordinary charcoal consists mainly of amorphous carbon, but also contains a small proportion of hydrocarbon compounds. Nitroglycerin consists of carbon combined with other elements, and in dynamite carbon is present not only as a component of the nitroglycerin but also as an essential constituent of the wood pulp or other active absorbent agent used.

It will accordingly be seen that the oxidation of carbon forms one of the principal reactions that occur in the chemical transformations involved in the decomposition of all commercial explosives. For that reason information in regard to the heat produced when carbon combines with oxygen in different proportions becomes of particular interest.

In regard to the reaction

$$C + O_2 = CO_2$$
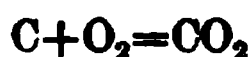
it has already been noted that the heat evolved amounts to 94,300 calories when the weights, expressed in grams, of the reacting substances taken correspond to their chemical equivalents. Under standard conditions of temperature and pressure the volume occupied by the molecular weight of a gas, expressed in grams, has been found to be constant for all gases, and to be equal to 22.4 liters. Since both the oxygen taken and the carbon dioxide produced in the reaction given are in grammolecular quantities, the oxygen represented in the equation will have a volume of 22.4 liters, and the carbon dioxide produced will have the same volume, when both are measured under standard conditions of temperature and pressure. It will, therefore, be seen that no change in volume occurs in this reaction when the components and the products of the reaction are taken in their actual state under ordinary conditions of temperature and pressure.

The specific heat of a substance is the ratio of the quantity of heat required to raise the temperature of a gram of the substance $1°$ C., to the quantity required to raise the temperature of a gram of water $1°$ C. The molecular heat of a substance is its specific heat multiplied by its molecular weight. The heat capacity of a mixture may be defined as the sum of the products obtained by multiplying the specific heat of each constituent by its weight in grams, or as the sum of the products obtained by multiplying the molecular heat of each constituent by the number of molecules of that constituent present.

The specific and molecular heats of gases have been found to increase with temperature, and, in general, it may be said that

(1) $c = a + bt$

where a is the molecular heat of the gas at $0°$ C., b the increment of the mean molecular heat of the gas for $1°$ C., c the mean molecular heat of the gas at constant volume from $0°$ C., to $t°$ C., and t the temperature to which the gas is raised.

The mean molecular heat of carbon dioxide between $0°$ and $3,000°$ C. has been measured, and is stated by Mallard and Le Chatelier[a] to be

$$c = 6.26 + 0.0037t$$

By the aid of this equation the temperature to which a given quantity of heat will raise a definite quantity of carbon dioxide can be calculated; and since the temperature to which a substance is raised by a given quantity of heat is expressed by the equation:

$$(2) \qquad t = \frac{Q}{c}$$

where Q is the number of calories available to raise the temperature of the material, c is the mean molecular heat of the material within the range over which its temperature is to be changed, and t is the resulting temperature, there is obtained by combining (1) and (2) and transposing the formula:

$$(3) \qquad t = \frac{-a + \sqrt{a^2 + 4b \times Q}}{2b}$$

which indicates the temperature to which the gram-molecular quantity of any gas at constant volume can be raised by a given quantity of heat, Q. It should be noted that these equations involving a, b, c, t, and Q are general ones and are true not only when c represents molecular heat, but also when it represents heat capacity, provided that in each case the value Q applies to the same quantity of material as the factor c.

In the reaction of carbon with oxygen to form carbon dioxide Q = 94,300, and in the formula for the molecular heat of carbon dioxide $a = 6.26$ and $b = 0.0037$. Substituting these values for a, b, and Q there is obtained:

$$t = \frac{-6.26 + \sqrt{(6.26)^2 + 4 \times 0.0037 \times 94,300}}{0.0074}$$

$$t = \frac{31.62}{0.0074}$$

$$t = 4,273°$$

The values that are of interest in regard to the reaction of carbon with oxygen to form carbon dioxide may be summarized as follows:

$$C + O_2 = CO_2 + 94,300 \text{ calories}$$
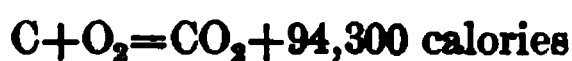
$\dfrac{94,300 \text{ calories}}{44}$ = calories per gram of reacting materials = 2,143 calories.

$\dfrac{94,300 \text{ calories}}{22.4}$ = calories per liter of resulting gas = 4,209 calories.

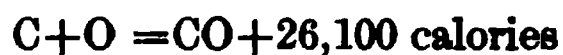$\dfrac{22.4}{44}$ = liters of gas per gram = 0.509 liters.

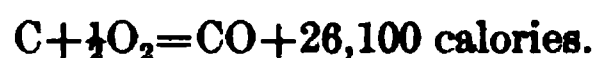Maximum temperature of reaction at constant volume = 4,273°.

[a] Annales des Mines, vol. 163, 1883, p. 524; Comptes Rendus, vol. 93, 1881, p. 1014.

REACTION OF CARBON WITH OXYGEN TO FORM CARBON MONOXIDE.

When carbon unites with oxygen to form carbon monoxide the reaction may be written:

$$C+O = CO+26,100 \text{ calories}$$

or

$$C+\tfrac{1}{2}O_2 = CO+26,100 \text{ calories.}$$

The latter form is the better as it expresses in a clearer manner the relationship of the volumes of the gases concerned in the reaction, but the first equation stated is the one more generally found in tables of thermochemical data. In both equations, of course, the same reaction is indicated.

It will be noted that from one-half gram-molecular volume of oxygen there results, in the reaction of carbon with oxygen to form carbon monoxide, 1 gram-molecular volume, or 22.4 liters, of carbon monoxide; and, as the volume occupied by solid carbon is so small as to be negligible, it will be seen that in the reaction there occurs an increase in volume such that the final gaseous product, carbon monoxide, has twice the volume of the oxygen originally present. Whenever a change in volume occurs in a chemical reaction taking place under ordinary conditions, the gases that are produced do work in overcoming the pressure of the atmosphere, and compensation must be made for the amount of energy that is expended in producing the increase in volume. In the tables of thermochemical data that are given on page 62, the components and products in every reaction are considered in their actual condition at 15° C., and accordingly the energy represented in any change in volume that has taken place in the reaction has already been allowed for.

When gases are formed within a closed space, so that they do not have to overcome the pressure of the atmosphere, their temperature will be higher by an amount that is determined by the energy that would otherwise be expended in overcoming atmospheric pressure. Consequently, as the decomposition of explosives under the condition of their actual employment involves their use in a closed space, such as a bore hole in some solid material, it is desirable to calculate the maximum temperature produced by explosives when the decomposition takes place under conditions of constant volume. As the data used give the results of reactions calculated to conditions of constant pressure, it is necessary to allow for the increased temperature due to the energy available as heat which under conditions of constant pressure would be employed in overcoming atmospheric pressure. As already noted, 1 gram-molecule of any gas occupies, under standard conditions of temperature and pressure, the volume of 22.4 liters. The standard condition of atmospheric pressure is represented by the pressure resulting from the weight of a column of mercury 76 centimeters high. Hence the pressure of 1 atmos-

phere on an area of 1 square centimeter is represented by the weight of a column of mercury 1 square centimeter in cross section and 76 centimeters in height. Since the specific gravity of mercury is 13.596, the pressure of such a column will be 76×13.596, or 1,033.3 grams per square centimeter.

The work done when 1 gram-molecule of gas (22,400 cubic centimeters) is formed against the pressure of 1,033.3 grams per square centimeter, is equivalent to overcoming a pressure equal to the weight of 1,033.3 grams through a vertical distance of 22,400 centimeters. This gives the energy required to overcome atmospheric pressure in the formation of 1 gram-molecule of any gas as equal to 23,145,920 gram-centimeter units, a gram-centimeter being taken as the energy required to lift the weight of 1 gram to a height of 1 centimeter against the earth's attraction. The earth's attraction at 45° latitude is taken as 980.6 dynes, and by the aid of this factor the work done in overcoming atmospheric pressure can be expressed in absolute units. However, since the mechanical equivalent of heat, or the equivalent of 1 calorie in terms of mechanical energy, has been directly determined as 42,719 gram-centimeter units, it is convenient to use this figure. Dividing 23,145,920 by 42,719 gives a quotient expressing the number of heat units represented in the formation of 1 gram-molecule of gas against atmospheric pressure. With the constants assumed in the calculation just made, the result is 542 calories, but the value used in this paper is 545 calories, because some of the constants used in the calculation have slightly different values from those stated.

In order that the equation

$$C+O=CO$$
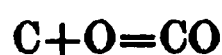
shall show the quantity of heat evolved when the reaction takes place under conditions of constant volume, it is necessary to add to the 26,100 calories representing the heat produced at constant pressure, the further sum of 272.5 calories, because of the increase of one-half gram-molecular volume that takes place.

Therefore, in the reaction at constant volume,

$$C+O=CO+26,372.5 \text{ calories.}$$

Hence, $Q=26,372.5$ calories.

The maximum temperature produced in the reaction is determined as follows:

In the equation $c=a+bt$ for carbon monoxide, $a=4.80$ and $b=0.0006$. Substituting these values and that of Q in equation (3) on page 21, gives:

$$t=\frac{-4.80+\sqrt{(4.80)^2+4\times0.0006\times26,372.5}}{0.0012}$$

$$t=\frac{4.492}{0.0012}$$

$$t=3,743°$$

The most important values relative to the reaction of carbon with oxygen to form carbon monoxide, at constant volume, are as follows:

$$C+O=CO+26,372.5 \text{ calories.}$$
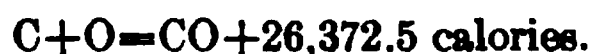
$$\frac{26,372.5}{28} = \text{calories per gram of reacting materials} = 942 \text{ calories.}$$

$$\frac{26,372.5}{22.4} = \text{calories per liter of resulting gas} = 1,177 \text{ calories.}$$

$$\frac{22.4}{28} = \text{liters of gas per gram} = 0.800 \text{ liters.}$$

Maximum temperature of reaction at constant volume $=3,743°$.

A comparison of these values with those for carbon dioxide brings out the interesting point that although the heat evolved in the reaction forming carbon dioxide is 94,300 calories, as against only 26,372.5 calories in the formation of carbon monoxide, yet the temperatures produced in the two cases are not far different, the maximum temperature in the reaction forming carbon dioxide being 4,273°, and that produced in the formation of carbon monoxide being 3,743°.

When the two calculations are compared it is noted that this result is brought about because of the specific heat of carbon monoxide being so much less than that of carbon dioxide, so that the smaller quantity of heat produced in the last reaction is sufficient to raise the gases formed to a temperature almost as high as when carbon dioxide is produced. This would indicate that it is not possible to materially lower the temperature of any reaction, in which carbon unites with oxygen, by varying the amount of carbon dioxide and carbon monoxide produced, so long as these gases alone are formed in the reaction. If, however, some other material is present in the reaction, or some other gas is formed which can share the heat with the main products of the reaction, it is quite evident that a decided lowering of the temperature would result.

The means that have been taken to lower the flame temperature of explosives without greatly decreasing their energy value will be discussed in another part of this paper, but at this point it seems desirable to show how markedly different the temperatures produced will be in the case of carbon dioxide and carbon monoxide when some other substance enters the reaction to share with the gaseous products the heat evolved by the oxidation of the carbon. As water, either free, in the form of moisture, or combined as water of crystallization, is a material frequently used in explosives to lower the flame temperature, the maximum temperature produced from 12 grams of carbon, burning to carbon dioxide and carbon monoxide, respectively, will now be calculated when 1 gram-molecule of free water is assumed to be present in the reaction.

REACTION OF CARBON WITH OXYGEN TO FORM CARBON DIOXIDE IN THE PRESENCE OF WATER.

The reaction under consideration is represented by the following equations:

$$C+O+H_2O \text{ (liquid)} = CO_2+H_2O \text{ (gas)}.$$
$$C+O_2=CO_2= \quad 94,300 \text{ calories}.$$
$$H_2O \text{ (liquid) to } H_2O \text{ (gas)} = -10,900 \text{ calories}.$$

$$\overline{\qquad 83,400 \text{ calories}.}$$

Compensation for change of volume, 545 calories.

$$\overline{\qquad 83,945 \text{ calories} = Q.}$$

In the equation

$$c=a+bt$$

for CO_2, $a=6.26$; $b=0.0037$; for H_2O, $a=5.61$; $b=0.0033$ and the mean molecular heats to be used in the calculation are:

For CO_2, $c= 6.26+0.0037t$.
For H_2O, $c= 5.61+ .0033t$.

Sum of mean molecular heats or heat capacity $c=11.87+ .0070t$.

Substituting these last values and that of Q in equation (3) on page 21, gives

$$t=\frac{-11.87+\sqrt{(11.87)^2+4\times0.0070\times83,945}}{0.014}$$
$$t=\frac{38.04}{0.014}$$
$$t=2,717°$$

In regard to this reaction the principal factors may be thus summarized:

$$\frac{83,945}{62} =\text{calories per gram of reacting materials}=1,354 \text{ calories}.$$

$$\frac{83,945}{2\times22.4} =\text{calories per liter of resulting gas}=1,874 \text{ calories}.$$

$$\frac{44.3}{62} =\text{liters of gas per gram}=0.722 \text{ liters}.$$

Maximum temperature of reaction at constant volume=2,717°.

REACTION OF CARBON WITH OXYGEN TO FORM CARBON MONOXIDE IN THE PRESENCE OF WATER.

The reaction of carbon with oxygen to form carbon monoxide when water is present may be expressed as follows:

$$C+O+H_2O \text{ (liquid)}=CO+H_2O \text{ (gas)}.$$
$$C+O=CO+26,100 \quad \text{calories}.$$
$$H_2O \text{ (liquid) to } H_2O \text{ (gas)}= -10,900 \quad \text{calories}.$$

$$\overline{\qquad 15,200 \quad \text{calories}.}$$

Compensation for change in volume $(1\frac{1}{2}\times545)= 817.5 \text{ calories}.$

$$\overline{\qquad 16,017.5 \text{ calories}=Q.}$$

In the equation

$$c=a+bt$$

for CO, $a = 4.80$, $b = 0.0006$; for H_2O, $a = 5.61$, $b = 0.0033$ and the mean molecular heats to be used in the calculation are:

$$\text{For CO, } c = 4.80 + 0.0006t.$$
$$\text{For } H_2O, c = 5.61 + .0033t.$$

Sum of mean molecular heats or heat capacity, $c = 10.41 + .0039t.$

Substituting these values as in the previous cases gives:

$$t = \frac{-10.41 + \sqrt{(10.41)^2 + 4 \times 0.0039 \times 16,017.5}}{2 \times 0.0039}$$

$$t = \frac{8.52}{0.0078}$$

$$t = 1,092°$$

In regard to this reaction, the principal factors may be thus summarized:

$$\frac{16,017.5}{46} = \text{calories per gram of reacting materials} = 348 \text{ calories.}$$

$$\frac{16,017.5}{2 \times 22.4} = \text{calories per liter of resulting gas} = 357 \text{ calories.}$$

$$\frac{44.8}{46} = \text{liters of gas per gram} = 0.974 \text{ liter.}$$

Maximum temperature of reaction, constant volume, $= 1,092°$

The very great reduction of flame temperature which results when carbon monoxide shares its heat with any substance of high specific heat is evident. One of the most important means used to produce explosives of low flame temperature is so to adjust the components of the explosives as to provide an excess of carbon over the quantity required to produce carbon dioxide. By such adjustment of the composition of the explosive, the formation of more or less carbon monoxide is brought about, and a gas of high specific heat, either water vapor or other gas, is provided to take up a portion of the heat produced in the reaction.

The following table presents the more important factors relative to the union of carbon and oxygen to form carbon monoxide and carbon dioxide in the four reactions just studied:

I....$C + O_2 = CO_2 + 94,300$ calories.
II....$C + O = CO + 26,100$ calories.
III....$C + O_2 + H_2O$ (liquid) $= CO_2 + H_2O$ (gas) $+ 83,945$ calories.
IV....$C + O + H_2O$ (liquid) $= CO + H_2O$ (gas) $+ 16,017.5$ calories.

	I	II	III	IV
Calories per gram of reacting materials	2,143	942	1,354	348
Calories per liter of resulting gas	4,209	1,177	1,874	357
Liters per gram	0.509	0.800	0.722	0.974
Maximum temperature of reaction, at constant volume	4,273°	3,743°	2,717°	1,092°

The quantity of water in the last two equations is greater in proportion to the amount of combustible material than would ever occur in an actual explosive. Accordingly, the equation is of theoretical interest only, but the very remarkable reduction in temperature from over 4,000°, in reaction I, to only about 1,000°, in reaction IV, shows clearly the lowering of the flame temperature that results when carbon monoxide shares its heat with water vapor.

MAXIMUM TEMPERATURE PRODUCED BY EXPLOSIVES HAVING NO SOLID PRODUCTS OF COMBUSTION.

What is called the "explosion" of any chemical compound or chemical aggregate is simply the result of a series of very rapid chemical and physical changes with their associated evolution of heat. In general, certain combustible elements in the explosive are oxidized, and the resulting gases are heated to a high temperature and greatly expanded by the heat evolved from the chemical reactions taking place. The point to be emphasized is, that the chemical reactions that take place during that rapid form of decomposition called "explosion" are not different in their fundamental nature from any of the ordinary chemical reactions.

The quantity of heat produced in any chemical reaction is an absolutely definite quantity, and as the effect of any given quantity of heat in expanding different amounts of gas is also well known, it is evident that information of decided value in regard to the flame temperature of any explosive may be obtained by suitable calculation. Attention has already been called to the fact that the quantity of heat evolved in any chemical reaction, or any set of chemical reactions, depends solely upon the initial and final states of the system, and is independent of the intermediate reactions.

As it is possible to analyze an explosive with considerable exactness, and to determine the constituents of the explosive and the percentage of each present, it is clear that the initial state of the explosive can be readily determined. By firing a suitable charge of the explosive in a cylinder strong enough to withstand the pressure produced, the products resulting from the explosive decomposition of the original material may be obtained, and by analysis of these the final state of the explosive system may be determined. The initial and final states of the explosive system being known, the quantity of heat evolved when the decomposition of the explosive is brought about may be accurately determined since all the factors are known.

The second part of the problem, the determination of the temperature to which a quantity of heat will raise the products of combustion, is at present not capable of very accurate solution, since the laws governing the specific heats of substances at high temperatures are but imperfectly known, and even the laws in regard to the change

in specific heats with increasing temperatures for many common substances are known only approximately.

By using the best values for specific heats that have been determined, information can be obtained in regard to the maximum temperature produced by many explosives. As some of the values entering into such calculations are not known with exactness, and as some are recognized to be mere approximations to true values, it should not be expected that calculations made in this way would have great accuracy. As new and better values are obtained for specific heats of substances at high temperatures, more accurate calculations will become possible, but even with the present data it is possible to obtain values that are of great importance in showing in what direction the change in composition of explosive materials should proceed, in order to obtain explosives of low-flame temperature.

As it is to be expected that such errors as enter into calculations of this sort will appear in all calculations equally, it is also apparent that the question whether one explosive will produce a higher flame temperature than another can be answered by calculation. And as the temperatures of explosives that have and of those that have not passed official tests in the presence of explosive mixtures of fire damp or coal dust with air have been calculated, the manufacturer may select, by the aid of such calculations made upon his explosives, those explosives that may most reasonably be expected to show favorable results upon being tested. He will thus greatly lessen the amount of work necessary in testing explosives and also increase his own chances of submitting explosives that shall show favorably in the official tests.

From such calculations as have already been made it would seem that any detonating explosive whose flame temperature, calculated by the method that will be followed in this paper, is lower than 1,700° C., will be reasonably sure to pass all of the tests required at the Pittsburgh station for inclusion in the "permissible" list. Detonating explosives having flame temperatures (calculated in the same manner) between 1,700° and 2,200° C. may or may not pass the tests. Those having temperatures near 1,700° C. may pass the tests; those whose temperatures exceed 2,000° C. are much less likely to do so. Explosives whose calculated flame temperatures lie above 2,200° C. may be assumed to be unworthy of test, since it is extremely doubtful if any explosive having so high a flame temperature could succeed in passing the tests, and even should it do so its charge limit would be so low as to make it unsuitable for general mining purposes.

In all cases where reactions are considered in which the products of explosive decomposition remain for some time under pressure while cooling (as is the case in experiments made in closed bombs, etc.),

there are a number of factors which must be given consideration to enable correct results concerning the maximum temperature produced to be determined. Recent investigations along this line have been made [a] showing the influence of secondary reactions as affecting the explosion temperature as calculated by thermochemical methods. Those who desire an exhaustive treatment of this subject may consult the references cited, but these factors will not be taken up here, since this paper is concerned mainly with the relative explosion temperatures of different explosives, and it is probable that such secondary effects as the reversible reaction between carbon dioxide and hydrogen, for example, or the formation of methane through the reaction of carbon monoxide and hydrogen, would not be sufficiently important to alter the relative positions of different explosives, when tested under identical conditions and calculated by the methods which will be outlined.

In a bulletin now being prepared for publication by the Bureau of Mines the author will take up in detail the influence of the formation of methane and other secondary compounds upon the flame temperatures and pressures involved in the use of permissible explosives, as well as of explosives used in blasting and quarrying. Until the data required for this paper can be assembled the flame temperatures as worked out by the methods herein outlined may be used as tentative results; it is believed that they will answer for most practical purposes.

THE MAXIMUM TEMPERATURE OF EXPLOSION OF NITRO-GLYCERIN.

The chemical changes that take place upon the explosion of nitroglycerin may be represented by the reaction:

$$4C_3H_5(ONO_2)_3 = 10H_2O + 6N_2 + 12CO_2 + O_2.$$

Analyses of the liquid and solid products resulting from the explosion of small quantities of nitroglycerin in strong steel cylinders have given results that practically accord with the above equation. The equation represents 4 molecular equivalents of nitroglycerin forming upon explosion 10 gram-molecules of water, 6 gram-molecules of nitrogen, 12 gram-molecules of carbon dioxide, and 1 gram-molecule of oxygen.

From such data it is possible to calculate the number of heat units evolved in the explosion of a given weight of nitroglycerin, the maximum pressure that would be produced if the gases were retained in the space originally occupied by the explosive, and the maximum temperature produced under the same conditions. The reacting

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[a] Poppenberg and Stephan, Zeitschr. ges. Schless-Sprengstoffw., vol. 5, pp. 281 and 305; pp. 266 and 310; and pp. 452 and 474.

Kast, Z., Zeitschr. ges. Schless-Sprengstoffw., vol. 5, pp. 205 and 248; and p. 376.

4 gram-molecules of nitroglycerin are decomposed, and therefore the number of calories represented by the formation of this nitroglycerin, if substracted from the number of calories represented by the heats of formation of all the final products, will give the number of heat units evolved when the above quantity of nitroglycerin is resolved into its decomposition products.

To calculate the maximum temperature reached it is necessary to consider the water produced in the reaction as existing in the gaseous state, and hence its heat formation is taken as 58,100 calories, instead of 69,000 calories, which would be the value if the determination had been carried out in a calorimeter and the resulting products brought to a temperature below the boiling point of water. The molecular weight of nitroglycerin is 227. As has been noted, it is convenient to use in thermochemical calculations the molecular weight of a substance expressed in grams. In the case of nitroglycerin, therefore, the quantity of material to be considered in the reaction is 227 grams. Owing to the fact that the volume of all gases can be expressed as a very simple relationship to their molecular weights it is convenient to consider in a reaction such a number of molecules as will cause all the figures for gases to come out in molecular quantities. The quantity of oxygen that is produced by the decomposition of 1 molecule of nitroglycerin is one-quarter molecule, and in this calculation, to avoid fractions, 4 gram-molecules of nitroglycerin are assumed to be taken.

To calculate the maximum temperature produced by the explosion of nitroglycerin, according to the reaction

$$4C_3H_5(ONO_2)_3 = 10H_2O + 6N_2 + 12CO_2 + O_2,$$

the products of explosion are assumed to occupy the same volume as the original explosive. The calculation is as follows:

Heat of formation of 10 gram-molecules of
gaseous water.............................=10×58,100 calories=   581,000 calories.
Heat of formation of 12 gram-molecules of
carbon dioxide.............................=12×94,300 calories=1,131,600 calories.
Compensation for 29 gram-molecules of gas,
at constant volume.......................=29×545   =   15,805 calories.
                                                               _____
                                                               1,728,405 calories.

The heat of formation of 1 gram-molecule of nitroglycerin is 98,900 calories (see table on p. 62) and the heat of formation of 4 gram-molecules will be 4×98,900 = 395,600 calories. This amount must be subtracted from the sum of the heats of formation of the products that result from the explosion of the nitroglycerin, thus giving 1,728,405 − 395,600 = 1,332,805, which is the number of calories evolved when 4 gram-molecules (908 grams) of nitroglycerin is decomposed in the manner expressed by the reaction given. It is con-

venient to represent the number of calories that are evolved in the course of a given reaction by the symbol Q, so that it may be said that

$$4C_3H_5(ONO_2)_3 = 10H_2O + 6N_2 + 12CO_2 + O_2$$

Q, at constant volume, water gaseous, = 1,332,805 calories.
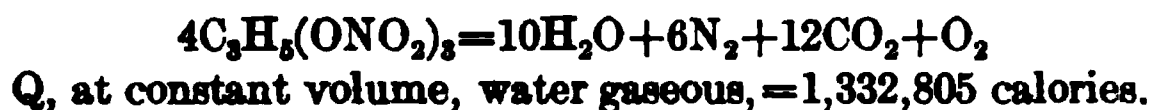
MAXIMUM TEMPERATURE PRODUCED.

The mean molecular heat or the mean specific heat of 1 gram-molecule of H_2O in the form of a gas, at constant volume, is $5.61 + 0.0033t$,[a] and of carbon dioxide $6.26 + 0.0037t$.[a] Nitrogen and oxygen have the same molecular heat, which is $4.80 + 0.0006t$.[a] Since the heat capacity of a mixture of gases, as previously defined, is the sum of the products obtained by multiplying the molecular heat of each constituent by the number of molecules of that constituent, the total heat capacity of the products of combustion is obtained as follows:

The products of combustion are $10H_2O + 6N_2 + 12CO_2 + O_2$. The mean molecular heat of each gas is represented by the equation $c = a + bt$.

Heat capacity of $10H_2O$ = 10×5.61 — $56.10 + 10 \times 0.0033t = 0.0330t$
Heat capacity of $12CO$ = 12×6.26 — $75.12 + 12 \times .0037t = .0444t$
Heat capacity of $6N + O$ = 7×4.80 — $33.60 + 7 \times .0006t = .0042t$
    Total heat capacity c.......... = $164.82 +$ $.0816t$

Substituting in the general equation these values for a and b and the value of Q determined above, the value of t is found:

$$t = \frac{-164.82 + \sqrt{(164.82)^2 + 4 \times 0.0816 \times 1,332,805}}{2 \times 0.0816}$$

$$t = \frac{515.02}{0.1632}$$

$$t = 3,155°$$

THE MAXIMUM TEMPERATURE OF EXPLOSION OF AMMONIUM NITRATE.

Berthelot[b] has found that ammonium nitrate may be decomposed in several different ways, according to the conditions under which its decomposition is brought about. As each of these types of decomposition involves a different chemical reaction and results in products having varying heats of formation, it is evident that the quantity of energy set free by the decomposing of a given amount of ammonium nitrate will depend upon which type of reaction occurs. It is difficult to cause pure ammonium nitrate to explode, but several explosives are in common use that contain large percentages of ammonium nitrate, and the reaction that the ammonium nitrate follows upon the explosion of these materials can be expressed. When associated with other explosive materials—as, for example, with small amounts of nitroglycerin—the detonation of ammonium nitrate is readily brought about. If the associated nitroglycerin is

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[a] Table 4, p. 61.   [b] Sur la Force des Matières Explosives, vol. 1, p. 21.

disregarded and only the reaction that the ammonium nitrate undergoes is considered, the detonation may be expressed by the following equation:

$$2NH_4NO_3 = 2N_2 + 4H_2O + O_2$$

Calculation of Q:

Heat of formation of $4H_2O$ $= 4 \times 58,100 = 232,400$ calories

Compensation for 7 gas vols. $= 7 \times \quad 545 = \quad 3,815$ calories

                                                         $236,215$ calories

Heat of formation of $2NH_4NO_3$ $= 2 \times 88,050 = 176,100$ calories

                                               $Q = \quad 60,115$ calories

Heat capacity of $4H_2O \quad = 4 \times 5.61 = 22.44 + 4 \times 0.0033t = 0.0132t$

Heat capacity of $2N_2 + O^2 = 3 \times 4.80 = 14.40 + 3 \times \quad .0006t = \dfrac{.0018t}{.0150t}$

Total heat capacity $c = 36.84 + 0.0150t$

Substituting these values for a, b, and Q in the general equation gives as the value of t:

$$t = \frac{-36.84 + \sqrt{(36.84)^2 + 4 \times 0.015 \times 60,115}}{2 \times 0.015}$$

$$t = \frac{33.62}{0.03}$$

$$t = 1,121°$$

The method of calculating the maximum temperature produced by an explosive, may be outlined as follows:

From the chemical analysis of the explosive the composition of the explosive expressed in terms of the molecular weights of its constituents is obtained by dividing the percentage of each constituent present by its molecular weight. These figures are then reduced to a more convenient form for calculation by dividing each one by the value obtained for the one lowest in amount. In this manner the number of gram-molecules of each constituent present is represented, when it is assumed that the amount of that constituent present in the smallest quantity amounts to 1 gram-molecule, and the set of figures obtained represents the initial composition of the explosive expressed in gram-molecules. By multiplying the number of gram-molecules of each substance by its molecular weight the total number of grams of material expressed in the equation is indicated. The initial condition of the explosive having been thus represented, the final condition is expressed in gram-molecular quantities by a similar series of calculations based upon the results of the analysis of the products of combustion. The gram-molecular quantities of the products of combustion are readily obtained from the per cent composition found by analysis and the total number of grams of material represented in the equation, as indicated above.

Should the cartridge of explosive analyzed represent absolutely the composition of the material fired in the gage, and should the

analysis of the products of combustion be absolutely exact, the two sides of the equation thus obtained should balance perfectly. But different cartridges of the same explosives vary somewhat; methods of analysis are not absolutely accurate; the collection of gaseous and liquid products of combustion is not easy, and the analysis of these products often suffers from many difficulties and inaccuracies. Hence it is evident that the balancing of the two sides of the equation is never exact, but with careful work the balancing will be sufficiently close to indicate with a very good degree of approximation the course of the explosive decomposition. Allowance is nearly always made in the weighed products of decomposition for the quantity of water which escapes as vapor when the cylinder in which the decomposition takes place is opened.

It will thus be seen that the first step in the calculation is to express the composition of the explosive and of the products of decomposition by chemical formulas, thus obtaining an equation representing the quantity of each material that enters into the reaction and the quantity of each product that results therefrom. From the complete equation representing the reaction the heats of formation of the constituents entering the explosion are determined. In this way the amount of energy that exists in the original material in a bound condition is found. By subtracting this amount from the total heat of formation of all the products resulting from the explosive decomposition there is obtained a measure (Q) of the amount of energy set free in the reaction indicated.

A given quantity, Q, being taken to represent the number of calories produced by the explosive reaction, it is only necessary to obtain the value that shall represent or shall closely approximate the heat capacity of the material in order to determine the temperature that will be reached. Taking all the products of combustion and adding together their heat capacities, a value is obtained representing the total heat capacity of the material of which the temperature is assumed to be raised by the amount of heat produced in the reaction.

The total heat capacity of the products of explosion being determined, the equation

$$t = \frac{Q}{c}$$

(in which c is the total heat capacity and Q is the number of calories produced by the explosion) enables the temperature to be determined.

The most convenient form in which to carry out this calculation has already been mentioned and is represented by the equation

$$t = \frac{-a + \sqrt{a^2 + 4b \times Q}}{2b}$$

where a and b are the two terms of the total heat capacity of the products of reaction, Q is the number of calories evolved in the reaction, and t is the maximum temperature produced.

The method of calculation with an explosive that has no solid products of combustion is shown in the following examples:

Calculation of the maximum temperature of an ammonium nitrate explosive.

1	2	8	4	5	6
Components.	Formula.	Composition.	Molecular weight.	Column 8 ÷ column 4	Column 5 ÷ 0.01284
Moisture................	H₂O................	0.60	18	0.03330	2.596
Nitroglycerin.............	C₃H₅(ONO₂)₃.......	8.37	227	.03687	2.871
Ammonium nitrate.......	NH₄NO₃...........	83.14	80	1.03900	80.92
Wood pulp..............	C₁₅H₂₂O₁₀..........	4.65	362	.01284	1.00
Mono-nitrotoluol.........	C₇H₇NO₂...........	3.24	137	.02365	1.84
.		100.00			

The following expression represents the composition of the explosive expressed in gram-molecules:

$$2.596H_2O + 2.871C_3H_5(NO_3)_3 + 80.92NH_4NO_3 + C_{15}H_{22}O_{10} + 1.84C_7H_7NO_2$$

SUM OF MOLECULAR WEIGHTS×NUMBER OF MOLECULES.

$$
\begin{aligned}
2.596\times 18 &= 46.73\\
2.871\times 227 &= 651.70\\
80.920\times 80 &= 6,474.00\\
1.000\times 362 &= 362.00\\
1.840\times 137 &= 252.10
\end{aligned}
$$

Weight in grams of explosive considered in the calculation...................... 7,786.53

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF EXPLOSIVE.

Grams.
Gaseous = 111.8
Liquid = 85.7
———
197.5
2.5 (loss)
———
200.0

Assuming this loss to be H₂O,

	Grams.		Per cent.
Total H₂O =	88.2	or	H₂O = 44.1
Total gas =	111.8		Gas = 55.9
	200.0		100.0

7,786.53×44.1 per cent=3,433.86, weight in grams of H₂O corresponding to 7,786.53 grams of explosive.

7,786.53×55.9 per cent=4,351.67, weight in grams of gases corresponding to 7,786.53 grams of explosive.

Analysis of gases.

	Per cent by volume.	Weight in 1 liter.	Per cent by weight.	Weight of 1 liter.
		Grams.		*Grams.*
CO₂	30.8	0.6052	41.01	1.965
O₂	1.5	.0214	1.45	1.429
N₂	67.7	.8489	57.54	1.254
	100.0	1.4755	100.00	....

Number of gram-molecules of each of the gaseous products from 7,786.53 grams of explosive:
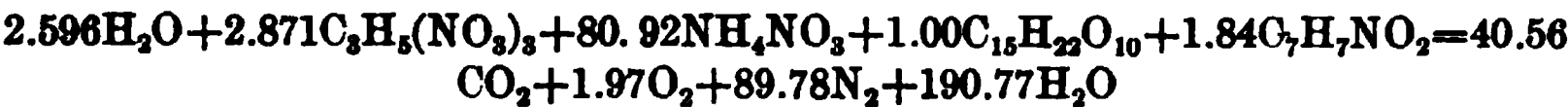
$$\frac{4{,}351.67 \times 0.4101}{44} = 40.56 \text{ molecules } CO_2$$

$$\frac{4{,}351.67 \times 0.0145}{32} = 1.97 \text{ molecules } O_2$$

$$\frac{4{,}351.67 \times 0.5754}{28} = 89.73 \text{ molecules } N_2$$

$$\frac{3{,}433.86}{18} = 190.77 \text{ molecules } H_2O$$

It being assumed, then, that the calculation deals with 7,786.53 grams of explosive, the following equation expresses, in gram-molecules, the quantities involved in the explosion:

$$2.596H_2O + 2.871C_3H_5(NO_3)_3 + 80.92NH_4NO_3 + 1.00C_{15}H_{22}O_{10} + 1.84C_7H_7NO_2 = 40.56 CO_2 + 1.97O_2 + 89.78N_2 + 190.77H_2O$$

The following comparison of the quantities of each element found on each side shows that the equation nearly balances:

INITIAL STATE.		FINAL STATE.
377.107	Hydrogen	381.54
284.875	Oxygen	275.83
36.493	Carbon	40.56
172.493	Nitrogen	179.56
870.968		877.49

Arranging the equation in a more convenient form:

INITIAL STATE.	FINAL STATE.
2.596H₂O	40.56CO₂
2.871C₃H₅(NO₃)₃	1.97O₂
80.920NH₄NO₃	89.78N₂
1.000C₁₅H₂₂O₁₀	190.77H₂O
1.840C₇H₇NO₂	
	323.08 number of gas volumes

HEATS OF FORMATION OF DECOMPOSITION PRODUCTS.	HEATS OF FORMATION OF ORIGINAL CONSTITUENTS.
Calories.	Calories.
$190.77 \times 58,100 = 11,083,737$	$2.596 \times 69,000 = 179,124$
$40.56 \times 94,300 = 3,824,848$	$2.871 \times 98,900 = 283,942$
$a\,323.08 \times 545 = 176,076$	$80.920 \times 88,050 = 7,125,006$
	$1.000 \times 463,360 = 463,360$
$15,084,661$	$1.84 \times 11,300 = 20,792$
	$8,072,224$

$Q = 15,084,661 - 8,072,224 = 7,012,437$ calories = heat evolved by explosion of 7,786.53 grams of explosive.

HEAT CAPACITY OF DECOMPOSITION PRODUCTS FROM 7,786.53 GRAMS OF EXPLOSIVE.

$$c = a + bt$$

$6.26 \times 40.56 = 253.9056 + 40.56 \qquad \times 0.0037t = 0.150072t$

$5.61 \times 190.77 = 1,070.2197 + 190.77 \qquad \times .0033t = .629541t$

$4.80 \times (1.97 + 89.78) = 440.4000 + (1.97 + 89.78) \times .0006t = .055050t$

Total heat capacity $c \quad = 1,764.5253 \qquad + \qquad .834663t$

Substituting the above values for Q, a, and b in the general equation gives the value of t:

$$t = \frac{-1,764.5253 + \sqrt{(1,764.5253)^2 + 4 \times 0.834663 \times 7,012,437}}{2 \times 0.834663}$$

$$t = \frac{3,386}{1.669326}$$

$$t = 2,028°\,C$$

SPECIFIC MEATS OF SOLID SUBSTANCES AT HIGH TEMPERATURES.

Solid substances are frequent among the decomposition products of explosives, and it becomes necessary to calculate the amount of heat absorbed in raising these solids to the temperature of explosion. Most solid substances show only a small increase of specific heat with increasing temperatures, but the increment is too great to be neglected. In cases in which direct determinations have been made it has been found that the rate of increase for different substances varies somewhat. Accordingly, there can exist no simple rule for deducing the specific heat of a substance at one temperature from data that may have been obtained at some other temperature. Most substances show an increase of specific heat with increasing temperature; this increase is gradual and quite regular so long as there is no physical or chemical change in the body. Near the melting point the specific heats of many substances change rapidly, and this is especially true as regards amorphous bodies passing into the liquid state.

From an extensive study of the specific heats of solids, Kopp deduced the law that their specific heat at ordinary temperatures is additive; that is, that the molecular heat of a solid (the product of the

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a Compensation for gas at constant volume.

specific heat times the molecular weight) is equal to the sum of the atomic heats of the elements which it contains. Kopp[a] found the atomic heat of most of the elements to be practically a constant (6.4), the following being the principal exceptions:

Sulphur, phosphorus, and boron..................................... 5. 4
Fluorine.. 5. 0
Silicon... 3. 8
Hydrogen... 2. 3
Oxygen... 4. 0
Carbon... 1. 8

By means of the above data the specific heats of solid compounds for which no experimental values are available may be calculated, but it is advisable to depend on the actual values obtained by experiment, where such are available.

As an example, calcium carbonate may be taken. The specific heat of calcium carbonate at ordinary temperatures has been found to be 0.203. The molecular heat of $CaCO_3$ would be $100 \times 0.203 = 20.3$. Calculation, by Kopp's law, gives 6.4 (atomic heat of calcium) + 1.8 (atomic heat of carbon) + 3×4 (atomic heat of 3 atoms of oxygen), the sum being 20.2. The agreement is close.

For higher temperatures it is found that the constants stated no longer hold true, and, as the temperatures for which the specific heats are desired in the calculations of explosives are in general higher than those that have been determined directly, the most convenient means of calculating specific heats appears to be to take advantage of the known increments of most elements through the range in which actual heat determinations have been made, and to assume that this same relation holds for higher temperatures. As actual determinations have been made up to a temperature of 1,600° C. in some cases, and as the temperatures for which figures are desired will usually be about 1,800° to 2,000° C., this will be seen to involve very small chances of error.

The specific heat of most elements has been found to increase by an amount equal to 0.0003 to 0.0005 of its value at zero for each increase of 1° C., and therefore, although not strictly accurate, the mean value 0.0004 may be used as representing a convenient approximation to the increase in specific heat of a solid for each increase of 1° C. from zero. Since in calculations, not the true specific heat, but the mean specific heat from zero to the temperature reached in the reaction is used, the value used will be one-half of the sum of the specific heats at zero and at the required temperature t. This value may be conveniently expressed by the equation

$$S_{m(0°-t°)} = S_0 + S_0 \times 0.0002t$$

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a Kopp, Hermann, Lieb. Ann. Suppl. 3, part 3, 1864-5, p. 289.

where $S_{m(o^\circ-t^\circ)}$ equals the mean specific heat of a substance from zero to the temperature t, and where S_0 equals the specific heat of the substance at zero.

Although very few determinations of specific heats of solids at high temperatures have been made, results indicate that the increase in specific heat becomes less at high temperatures, but in all cases has a positive value.

For a considerable range on each side of 2,000° C. it is believed that the use of the increment 0.0002, in the mean specific heat, for each degree of rise in temperature, gives results that are very close to the true value, and although it is clear that for lower temperatures this increment would not give high enough values, yet for such temperatures as those dealt with it would seem to give reliable results. As another example take calcium silicate. This substance, $CaSiO_3$ (molecular weight 116), has a specific heat at 0° C. of 0.174 [a] and a mean specific heat between 0° and 1,100° C. of 0.2404. Its molecular heat would then be $116 \times 0.174 = 20.18$ at 0° C. and $116 \times 0.2404 = 27.88$ for the mean between 0° and 1,100° C.

Calculating by Kopp's law, the molecular heat at 0° C. would be found to be 6.4 (atomic heat of calcium) + 3.8 (atomic heat of silicon) + 3×4 ($3 \times$ atomic heat of oxygen), a total of 22.2, as against the experimental value of 20.18.

Calculating the mean specific heat between 0° and 1,000° C. by the formula

$$S_{m(o^\circ-t^\circ)} = S_0 + S_0 \times 0.0002t$$
$$S_{m(o^\circ-1,100^\circ)} = 0.174 + 0.174 \times 0.0002 \times 1,100$$
$$= 0.212, \text{ mean specific heat between 0° and 1,100°}$$

Then the mean molecular heat is $0.212 \times 116 = 24.62$, as compared with the experimental value of 27.88.

The application of these data to the solution of problems relative to explosions yielding solid products will now be considered.

THE MAXIMUM TEMPERATURE OF EXPLOSIVES HAVING SOLID PRODUCTS OF COMBUSTION.

In the case of explosives yielding solid products of combustion it is necessary to consider the amount of heat required to raise the temperature of such solids as are produced from the initial to the final temperature. This causes the value of c in the equation to have a somewhat different value than is the case when no solids need be considered. From the rules given in the preceding chapter the specific heat at zero of all solids entering the reaction may be calculated, this forming the a term in the equation

$$c = a + bt.$$

a Walter P. White, Am. Jour. Science, vol. 28, Oct., 1909, p. 334.

The value of the b term is readily determined from the equation

$$S_{m(o^\circ_1 - t^\circ)} = S_0 + S_0 \times 0.0002t$$

which shows that b is represented by $S_0 \times 0.0002$. Making the proper allowance for the specific heats of the solids concerned, the calculation is carried out in exactly the same manner as for explosives having no solid products of combustion. The following examples show the work in full:

Temperature of explosion of a black blasting powder.

1	2	8	4	5	6
Components.	Formula.	Composition.	Molecular weight.	Column 8 / Column 4	Column 5 / 0.0444
Moisture	H_2O	0.80	18	0.0444	1.00
Sodium nitrate	$NaNO_3$	70.57	85	.8302	18.70
Sulphur	S	10.89	32	.3403	7.66
Charcoal	C	17.74	12	1.4800	33.40

The following expression represents the composition of the explosive in gram-molecules:

$$1.00H_2O + 18.70 + NaNO_3 + 7.66S + 33.40C$$

SUM OF MOLECULAR WEIGHTS × NUMBER OF MOLECULES.

$$1.00 \times 18 = \quad 18$$
$$18.70 \times 85 = 1,590$$
$$7.66 \times 32 = \quad 245$$
$$33.40 \times 12 = \quad 401$$

Weight in grams of explosive considered in the calculation.......2,254

PRODUCTS OF COMBUSTION FROM 300 GRAMS POWDER.

	Grams.	Per cent.
Gas	=154.4=	51.47
Solids	=141.5=	47.17
Water =	4.1=	1.36
	300.0=	100.00

SOLID PRODUCTS.

Soluble   91.2 per cent ×141.5=129.05 grams=43.02 per cent of total products.
Insoluble 8.8 per cent ×141.5= 12.45 grams= 4.15 per cent of total products.

47.17 per cent.

INSOLUBLE SOLIDS.

Carbon=12.45 grams=4.15 per cent of products.

SOLUBLE SOLIDS.

129.05 grams=43.02 per cent of products.

H_2S in gases=8.24 per cent (154.4 grams gases) (S in H_2S=94.1 per cent)

$$0.0824 \times 154.4 \times 0.941 = 11.97 \text{ grams} = S \text{ in } H_2S$$

$$0.1089 \times 300 = 32.67 \text{ grams} = S \text{ total in powder (300 grams)}$$

$$32.67 - 11.97 = 20.70 \text{ grams} = S \text{ in solids}$$

assumed to be combined as Na_2SO_4 and Na_2S_2 in the proportion of

$$1Na_2SO_4 \text{ to } 2Na_2S_2.[a]$$

In $1Na_2SO_4 : 2Na_2S_2$, the proportion of S is as 1 is to 4, therefore

$$\frac{20.70}{5} = 4.14 \text{ grams S in } Na_2SO_4$$

and

$$4.14 \times 4 = 16.56 \text{ grams S in } Na_2S_2$$

$$\overline{20.70 \text{ grams S in solids}}$$

$$\frac{4.14 \times 100}{22.54} = 18.37 \text{ grams } Na_2SO_4 = 6.12 \text{ per cent of total products}$$

$$\frac{16.56 \times 100}{58.18} = 28.46 \text{ grams } Na_2S_2 = 9.49 \text{ per cent of total products.}$$

Deducting (18.37+28.46) from the total weight of soluble solids (129.05 grams leaves 82.22 grams Na_2CO_3.

$$82.22 \text{ grams } Na_2CO_3 = 27.41 \text{ per cent of total products.}$$

The above quantities of solids are produced by the explosion of 300 grams of powder. Changing these values to gram-molecular quantities produced by the explosion of 2,254 grams of powder gives the following:

$$\frac{6.12 \times 2,254}{142 \times 100} = 0.97 \text{ molecules } Na_2SO_4$$

$$\frac{9.49 \times 2,254}{110 \times 100} = 1.95 \text{ molecules } Na_2S_2$$

$$\frac{27.41 \times 2,254}{106 \times 100} = 5.83 \text{ molecules } Na_2CO_3$$

$$\frac{4.15 \times 2,254}{12 \times 100} = 8.00 \text{ molecules C.}$$

GASEOUS PRODUCTS.

ANALYSES OF GASES.

	Per cent by volume.	Weight in 1 liter.	Per cent by weight.	Weight of 1 liter.
		Grams.		*Grams.*
CO_2	49.7	0.9766	60.81	1.965
CO	10.8	.1351	8.41	1.251
H_2S	8.7	.1324	8.24	1.522
H_2	1.8	.0016	.10	.0895
CH_4	.6	.0043	.27	.7150
N_2	28.4	.3561	22.17	1.254
	100.0	1.6061	100.00	

$0.5147 \times 2254 = 1160 = $ weight in grams of gases produced by explosion of 2,254 grams of powder.

* Walke, W., Lectures on Explosives, pp. 147, 151.

GRAM-MOLECULES OF GASES PRODUCED BY EXPLOSION OF 2,254 GRAMS OF POWDER.

$$\frac{60.81 \times 1,160}{44 \times 100} = 16.03 \text{ molecules } CO_2$$

$$\frac{8.41 \times 1,160}{28 \times 100} = 3.48 \text{ molecules } CO$$

$$\frac{8.24 \times 1,160}{34 \times 100} = 2.81 \text{ molecules } H_2S$$

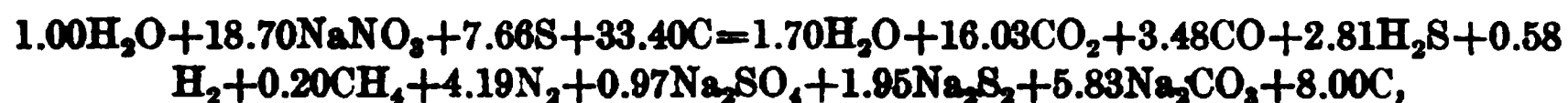$$\frac{0.10 \times 1,160}{2 \times 100} = 0.58 \text{ molecules } H_2$$

$$\frac{0.27 \times 1,160}{2 \times 100} = 0.20 \text{ molecules } CH_4$$

$$\frac{22.17 \times 1,160}{28 \times 100} = 9.19 \text{ molecules } N_2$$

LIQUID PRODUCTS.

$$\frac{1.36 \times 2,254}{18 \times 100} = 1.70 \text{ molecules } H_2O.$$

Combining the expressions found for the original explosive and for its explosion products gives the following equation which represents, in gram-molecules, the decomposition of 2,254 grams of explosive:

$1.00H_2O + 18.70NaNO_3 + 7.66S + 33.40C = 1.70H_2O + 16.03CO_2 + 3.48CO + 2.81H_2S + 0.58$
$H_2 + 0.20CH_4 + 4.19N_2 + 0.97Na_2SO_4 + 1.95Na_2S_2 + 5.83Na_2CO_3 + 8.00C,$

or, arranging in more convenient form:

INITIAL STATE.	FINAL STATE.	
1.00H_2O	1.70H_2O	
18.70NaNO_3	16.03CO_2	
7.66S	3.48CO	
33.40C	2.81H_2S	
	.58H_2	33.99 gram-molecules of gas
	.20CH_4	
	9.19N_2	
	.97Na_2SO_4	
	1.95Na_2S_2	
	5.83Na_2CO_3	
	8.00C	

HEATS OF FORMATION OF DECOMPOSITION PRODUCTS.		HEATS OF FORMATION OF ORIGINAL CONSTITUENTS.	
	Calories.		Calories.
1.70 × 58,100 =	98,770	1.00 × 69,000 =	69,000
16.03 × 94,300 =	1,511,629	18.70 × 111,250 =	2,080,375
3.48 × 26,100 =	90,828		
2.81 × 2,700 =	7,587		2,149,375
.20 × 18,900 =	3,780		
.97 × 328,600 =	318,742		
1.95 × 88,200 =	171,990		
5.83 × 272,600 =	1,589,258		
a 34.00 × 545 =	18,530		
	3,811,114		

a Compensation for 34 gram-molecules of gas at constant volume.

$Q = 3,811,114 - 2,149,375 = 1,661,739$ calories=heat evolved by explosion of 2,254 grams of explosive.

HEAT CAPACITY OF DECOMPOSITION PRODUCTS FROM 2,254 GRAMS OF EXPLOSIVE.

$$c = a + bt$$

$$1.70 \times 5.61 = 9.537 + 1.70 \times 0.0033t = 0.00561t$$
$$16.03 \times 6.26 = 100.348 + 16.03 \times .0037t = .05931t$$
$$\left.\begin{array}{c}3.48 \\ .58 \\ 9.19\end{array}\right\} \times 4.80 = 63.600 + (.58) \times .0006t = .00795t$$
$$2.81 \times 6.30 = 17.703 + 2.81 \times .0005t = .00141t$$
$$.20 \times 7.10 = 1.420 + .20 \times .0005t = .00010t$$
$$.97 \times 32.83 = 31.845 + .97 \times .00657t = .00637t$$
$$1.95 \times 19.00 = 37.050 + 1.95 \times .00380t = .00741t$$
$$5.83 \times 26.08 = 152.046 + 5.83 \times .00522t = .03043t$$
$$8.00 \times 6.40 = 51.200 + 8.00 \times .00128t = .01024t$$

Total heat capacity $c = 464.749 + \qquad\qquad .12883t$

Substituting the above values for Q, a, and b in the general equation gives the value of t:

$$t = \frac{-464.749 + \sqrt{(464.749)^2 + 4 \times 0.12883 \times 1,661,739}}{2 \times 0.12883}$$

$$t = \frac{570.77}{0.25766}$$

$$t = 2,215°$$

Calculation of the maximum temperature of an explosive containing an excess of carbon.

1	2	3	4	5	6
Components.	Formula.	Composition.	Molecular weight.	$\dfrac{\text{Column 3}}{\text{Column 4}}$	$\dfrac{\text{Column 5}}{0.0169}$
Moisture.....................	H_2O	4.05	18	0.2250	13.31
Nitroglycerin...............	$C_3H_5(ONO_2)_3$.......	24.92	227	.1098	6.50
Barium nitrate.............	$Ba(NO_3)_2$.............	4.42	261	.0169	1.00
Wood pulp.................	$C_{15}H_{22}O_{10}$............	34.60	362	.0956	5.66
Potassium nitrate.........	KNO_3................	25.37	101	.2512	14.86
Starch.....................	$C_6H_{10}O_5$.............	6.64	162	.0411	2.43
		100.00			

The following expression represents the composition of the explosive in gram-molecules:

$$13.31H_2O + 6.50C_3H_5(NO_3)_3 + 1.00Ba(NO_3)_2 + 5.66C_{15}H_{22}O_{10} + 14.86KNO_3 + 2.43C_6H_{10}O_5.$$
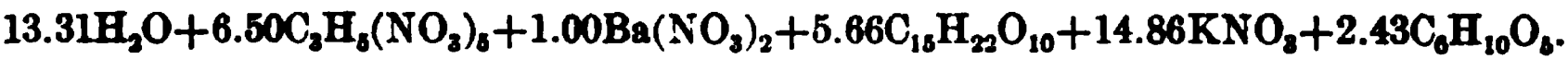
SUM OF MOLECULAR WEIGHTS × NUMBER OF MOLECULES.

$$13.31 \times 18 = 239.60$$
$$6.50 \times 227 = 1,475.50$$
$$1.00 \times 261 = 261.00$$
$$5.66 \times 362 = 2,048.92$$
$$14.86 \times 101 = 1,500.86$$
$$2.43 \times 162 = 393.66$$

Weight in grams of explosive considered in the calculation.............................5,919.54

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF EXPLOSIVE.

Grams.
Gas   = 130.3
Solids = 49.0
Liquid = 12.4
                    _____
                    191.7
                      8.3 (loss)
                    _____
                    200.0

Let it be assumed that the above loss of products is H_2O, then

Total H_2O = 12.4 + 8.3 = 20.7 grams = 10.35 per cent of products
Gas   = 130.3 grams = 65.15 per cent of products
Solids   = 49.0 grams = 24.50
                        _____   _____
                        200.0 grams = 100.0

SOLID PRODUCTS.

Insoluble 23.9 per cent × 49 = 11.71 grams = 5.86 per cent of total products
Soluble   76.1 per cent × 49 = 37.29 grams = 18.64 per cent of total products

INSOLUBLE SOLIDS.

4.42 per cent $Ba(NO_3)_2$ = 8.84 grams $Ba(NO_3)_2$ in 200 grams powder
                = 6.71 grams $BaCO_3$ = 3.35 per cent of total products.

Deducting 6.71 grams $BaCO_3$ from 11.71 grams total insoluble solids leaves 5.00 grams assumed to be free carbon = 2.5 per cent of total products.

SOLUBLE SOLIDS.

50.74 grams = KNO_3 in 200 grams powder (0.2537 × 200 = 50.74 grams)
37.29 grams soluble solids assumed to be K_2CO_3 + $KHCO_3$
x grams K_2CO_3 = 0.565 x grams K
$(37.29 - x)$ grams $KHCO_3$ = 0.39 $(37.29 - x)$ grams K
50.74 grams KNO_3 = 0.386 × 50.74 grams K = 19.585 grams K
$0.565x + 0.39 (37.29 - x) = 19.585$
$0.565x + 14.54 - 0.39x = 19.585$
$0.175x = 5.04$
$x = 28.8$ grams K_2CO_3 = 14.4 per cent of total products
$37.29 - x = 8.49$ grams $KHCO_3$ = 4.25 per cent of total products

Changing the above quantities of solids to gram-molecular quantities produced by explosion of 5,919.54 grams of explosive gives the following:

$$\frac{3.33 \times 5,919.54}{197 \times 100} = 1.00 \text{ molecules } BaCO_3$$

$$\frac{2.5 \times 5,919.54}{12 \times 100} = 12.33 \text{ molecules } C$$

$$\frac{14.4 \times 5,919.54}{138 \times 100} = 6.17 \text{ molecules } K_2CO_3$$

$$\frac{4.25 \times 5,919.54}{100 \times 100} = 2.52 \text{ molecules } KHCO_3$$

GASEOUS PRODUCTS.

ANALYSIS OF GASES.

	Per cent by volume.	Weight in 1 liter.	Per cent by weight.	Weight of 1 liter.
CO_2	18.9	0.371	36.52	1.965
CO	36.3	.454	44.69	1.250
H_2	29.1	.026	2.56	.0695
N_2	9.9	.124	12.20	1.254
CH_4	5.8	.041	4.03	.715
		1.016	100.00	

$$\frac{65.15 \times 5,919.54}{100} = 3,856 = \text{weight in grams of gases produced by explosion of 5,919.54}$$
grams of explosive.

$$\frac{3,856 \times 36.52}{44 \times 100} = 32.01 \text{ molecules } CO_2$$

$$\frac{3,856 \times 44.69}{28 \times 100} = 61.54 \text{ molecules } CO$$

$$\frac{3,856 \times 2.56}{2 \times 100} = 49.36 \text{ molecules } H_2$$

$$\frac{3,856 \times 12.2}{28 \times 100} = 16.80 \text{ molecules } N_2$$

$$\frac{3,856 \times 4.03}{16 \times 100} = 9.71 \text{ molecules } CH_4$$

LIQUID PRODUCTS.

$$\frac{10.35 \times 5,919.54}{18 \times 100} = 34.04 \text{ molecules } H_2O.$$

Combining the expressions found for the original explosive and for its explosion products gives the following equation, which represents in gram-molecules the decomposition of 5,919.54 grams of explosive:

$13.31H_2O + 6.50C_3H_5(NO_3)_3 + 1.00Ba(NO_3)_2 + 5.66C_{15}H_{22}O_{10} + 14.86KNO_3 + 2.43C_6H_{10}O_5$
$= 34.04H_2O + 32.01CO_2 + 61.54CO + 49.36H_2 + 16.80N_2 + 9.71CH_4 + 6.17K_2CO_3 + 12.33C$
$+ 2.52KHCO_3 + 1.00BaCO_3$
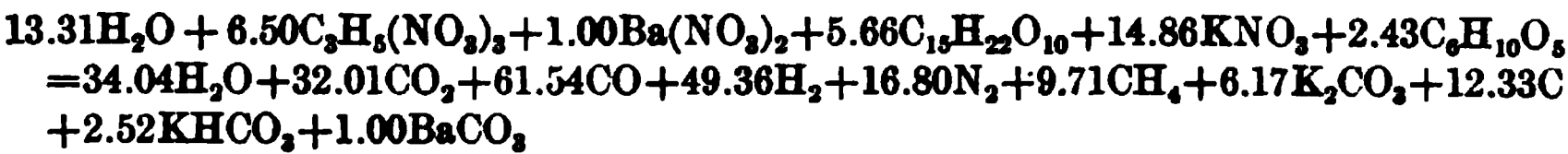
or, rearranging:

INITIAL STATE.	FINAL STATE.
$13.31H_2O$	$34.04H_2O$
$6.50C_3H_5(NO_3)_3$	$32.01CO_2$
$1.00Ba(NO_3)_2$	$61.54CO$
$5.66C_{15}H_{22}O_{10}$	$49.36H_2$
$14.86KNO_3$	$16.80N_2$
$2.43C_6H_{10}O_5$	$9.71CH_4$
	$12.33C$
	$6.17K_2CO_3$
	$2.52KHCO_3$
	$1.00BaCO_3$

203.46 gram-molecules of gas.

HEATS OF FORMATION OF DE-COMPOSITION PRODUCTS.	HEATS OF FORMATION OF ORIGINAL CONSTITUENTS.
Calories.	Calories.
34.04× 58,100=1,977,724	13.31× 69,000= 918,390
32.01× 94,300=3,018,543	6.50× 98,900= 642,850
61.54× 26,100=1,606,194	1.00×228,400= 228,400
9.71× 18,900= 183,519	5.66×463,360=2,622,617
6.17×281,100=1,734,387	14.86×119,500=1,775,770
2.52×233,300= 587,916	2.43×225,900= 548,937
1.00×285,600= 285,600	
a 203.46× 545= 110,886	6,736,964
9,504,769	

Q=9,504,769−6,736,964=2,767,805 calories=heat evolved by explosion of 5,919.54 grams of explosive.

HEAT CAPACITY OF DECOMPOSITION PRODUCTS FROM 5,919.54 GRAMS OF EXPLOSIVE.

$$c=a+bt$$

34.04 × 5.61 =	190.96+ 34.04 ×0.0033t	=0.112332t
32.01 × 6.26 =	200.38+ 32.01 × .0037t	= .118437t
61.54	(61.54)	
49.36 }× 4.80 =	612.96+(49.36)× .0006t	= .076620t
16.80	(16.80)	
9.71 × 7.10 =	68.94+ 9.71 × .0005t	= .004855t
6.17 ×28.428=	175.40+ 6.17 × .00568t=	.035046t
2.52 ×20.600=	51.71+ 2.52 × .00416t=	.010483t
1.00 ×21.670=	21.67+ 1.00 × .00433t=	.004330t
12.33 × 6.4 =	78.91+ 12.33 × .00128t=	.015782t

Total heat capacity, c, =1,400.93+   .377885t

Substituting the above values for Q, a, and b in the general equation gives the value of t.

$$t=\frac{-1,400.93+\sqrt{(1,400.93)^2+4\times0.377885\times2,767,805}}{2\times0.377885}$$

$$t=\frac{1,078}{0.75577}$$

$$t=1,426°$$

COMPARISON OF TWO EXPLOSIVES.

The two following explosives contain the same constituents in very nearly the same proportions; one passes and the other does not pass a test at the Pittsburgh testing station. Comparison of the two shows how small a difference in composition may determine whether or not an explosive will pass a required test.

---

a Compensation for 203.46 gram-molecules of gas at constant volume,

The chemical composition of the explosive that passed the test is as follows:

Moisture	4.70
Nitroglycerin	24.61
Sodium nitrate	44.22
Calcium carbonate	.81
Magnesium carbonate	2.09
Sulphur	.67
Coal	22.90
	100.00

The constituent noted as "coal" in this powder is a mixture of coke with a natural coal, and by determination of its volatile matter its composition is assumed to be expressed by the formula:

$$C_{75}H_{50}O_2N$$

The products of combustion from this explosive were as follows:

Gases	59.55
Solids	36.50
Liquids (H_2O)	3.95
	100.00

The composition of the gaseous products, in parts by volume, were as follows:

CO_2	13.7
CO	43.5
H_2	22.8
CH_4	1.6
N_2	18.4
	100.0

The solid products consisted of calcium carbonate, magnesium carbonate, carbon, sodium sulphide, and sodium carbonate.

The decomposition of the explosive was assumed to be represented by the following equation:

$32.23H_2O + 13.38C_2H_5(NO_3)_3 + 1.00CaCO_3 + 3.07MgCO_3 + 2.58S + 64.22NaNO_3 + 2.84C_{75}H_{50}O_2N = 27.10H_2O + 41.80CO_2 + 132.80CO + 69.80H_2 + 4.87CH_4 + 56.30N_2 + 2.60Na_2S + 30.72Na_2CO_3 + 1.00CaCO_3 + 3.07MgCO_3 + 57.40C.$
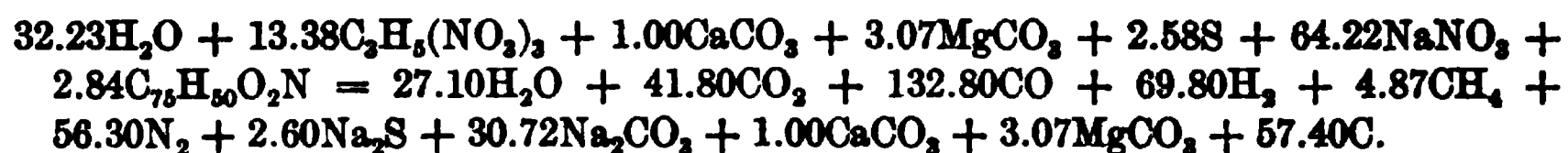
By calculating from the above equation the maximum temperature of explosion, in the same manner as has been done in previous cases, there is obtained:

$$Q = 6,879,599 \text{ calories} \qquad c = 2,982.214 + 0.66025t$$

$$t = \frac{-2,982.214 + \sqrt{(2,982.214)^2 + 4 \times 0.66025 \times 6,879,599}}{2 \times 0.66025}$$

$$t = 1,631°$$

The analysis of the explosive that did not pass the tests was as follows:

Moisture	3.78
Nitroglycerin	18.14
Sodium nitrate	56.95
Calcium carbonate	.92
Magnesium carbonate	2.67
Sulphur	.36
Coal	17.17
	100.00

The coal mixture in this powder was identical with that of the other powder just calculated. The products of decomposition from this explosive were as follows:

	Per cent.
Gases	48.55
Solids	42.10
Liquid (H_2O)	9.35
	100.00

The composition of the gaseous products in percentage by volume was as follows:

	Per cent.
CO_2	25.5
CO	30.0
H_2	11.8
CH_4	2.2
N_2	30.5
	100.0

The solid products were: Calcium carbonate, magnesium carbonate, free carbon, sodium sulphide, and sodium carbonate, as before, and the decomposition of the explosive was assumed to be as follows:

$22.82H_2O + 8.7C_3H_5(NO_3)_3 + 72.84NaNO_3 + 1.00CaCO_3 + 3.45MgCO_3 + 1.22S + 1.87C_{76}H_{60}O_2N = 56.51H_2O + 46.81CO_2 + 55.07CO + 21.65H_2 + 4.03CH_4 + 56.13N_2 + 1.00CaCO_3 + 3.46MgCO_3 + 35.43C + 1.22Na_2S + 35.22Na_2CO_3.$
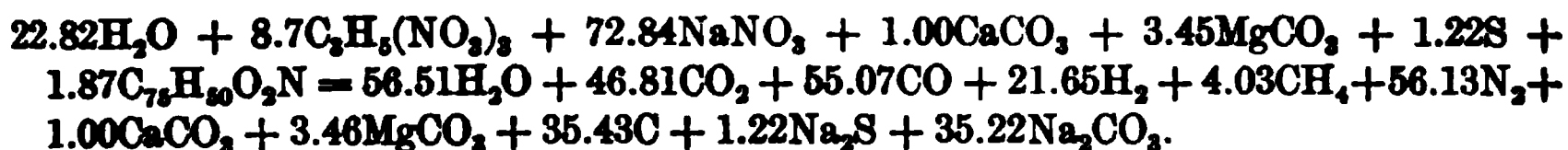
By calculating from this equation the maximum temperature of explosion, there is obtained:

$$Q = 8,322,270 \text{ calories.} \qquad c = 2,524.934 + 0.687582t$$

$$t = \frac{-2,524.934 + \sqrt{(2,524.934)^2 + 4 \times 0.687582 \times 8,322,270}}{2 \times 0.687582}$$

$$t = 2,098°$$

It is interesting to note that the difference of about 500° C. in the maximum temperature shown by these two explosives is enough to determine the success of one and the failure of the other in the tests required at the Pittsburgh station. It seems probable in the case of

some explosives that pass all but one of the tests at the Pittsburgh station, that a change in composition effecting as slight a reduction of flame temperature as 100° or 200° C. might put them upon the permissible list, since it is probable that a very small variation in flame temperature is the determining factor. One should not infer from this that it is desirable that explosives should pass the requirements by the narrowest possible margin of flame temperature. An explosive whose flame temperature is quite low can probably be used in larger amounts without grave danger than can an explosive whose flame temperature is higher. But explosives having desirable properties may, as regards flame temperature, approach close to the ignition limit. In the case of such explosives it should always be possible by the selection of suitable means to so reduce the flame temperature as to enable the explosive to pass the tests.

RESULTS OF DIRECT CALORIMETRIC DETERMINATIONS.

. In the methods of calculation already shown it has been assumed that no knowledge was available in regard to the explosive reaction other than the analysis of the original explosive and that of the resulting products.

By firing a charge of an explosive in a suitable calorimetric bomb it is possible to obtain a direct value for Q, the amount of heat evolved in the chemical reaction taking place at the moment of explosion, and the value of Q has been so determined for a number of explosives. A comparison of the values thus obtained with those found by calculation is of interest; it shows that the results obtained by calculation are in very close agreement with the values obtained by direct determination.

In order that the results from direct determinations may be comparable with those obtained by calculation, one should remember that the direct readings in a calorimetric bomb must be corrected for the amount of heat set free in the condensation to liquid water of all the water vapor present. The reactions involved in any explosion take place at a temperature higher than that which would permit the condensation to liquid water of the water formed, but the calorimetric bomb is itself immersed in water, and the resulting products of explosion are maintained at a temperature lower than that at which gaseous water is stable. Accordingly, all of the water vapor formed occurs in the products as liquid water, and the amount of heat evolved, as shown by the calorimeter, is higher by the value representing the latent heat of evaporation of this water. As an example of the calculation of the temperature of explosion, as determined by direct calorimetric readings, the case of the ammonium nitrate explosive previously calculated on pages 34 to 36

may be taken. The reaction considered in this explosive was as follows:

$$2.596H_2O + 2.871C_3H_5(NO_3)_3 + 80.92NH_4NO_3 + 1.00C_{15}H_{22}O_{10} + 1.84C_7H_7NO_2 = 40.56$$
$$CO_2 + 1.97O_2 + 89.78N_2 + 190.77H_2O.$$
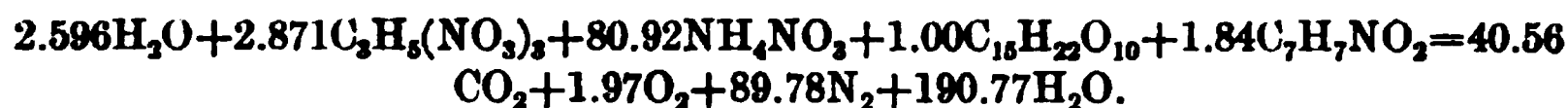
By direct reading of the calorimeter it was found that 1,245 calories were evolved per gram of explosive taken, the water being liquid. As the amount of H_2O in each gram of total products is found to be 0.441 gram, and as the change from gaseous water to liquid water evolves 10,900 calories for each gram-molecule of water taken (18 grams), the correction in this example for liquid water is:

$$\frac{10900 \times .441}{18} = 267.6 \text{ calories per gram.}$$

The evolution of heat being 1,245 calories per gram of material, and the correction being 267.6 calories per gram, there results a net evolution of heat per gram of reacting substance of 977.4 calories, and for the 7,786 grams of material in the reaction,

$$Q = 7,610,036 \text{ calories.}$$

Calculation from this value gives:

$$t = \frac{-1,764.5253 + \sqrt{(1,764.5253)^2 + 4 \times .834663 \times 7,610,036}}{2 \times 0.834663}$$

$$t = 2142°$$

By calculation from the analysis of the explosive, the value of Q was found to be 7,012,437. The value of t from this is:

$$t = \frac{-1,764.5253 + \sqrt{(1,764.5253)^2 + 4 \times 0.834663 \times 7,012,437}}{2 \times 0.834663}$$

$$t = 2028°$$

Proceeding in a similar manner with the black powder calculated on pages 39 to 42 the following equation is obtained:

$$1.00H_2O + 18.70NaNO_3 + 7.66S + 33.40C = 1.70H_2O + 16.03CO_2 + 3.48CO + 2.81H_2S +$$
$$0.58H_2 + 0.20CH_4 + 9.19N_2 + 0.97Na_2SO_4 + 1.95Na_2S_2 + 5.83Na_2CO_3 + 8.00C.$$
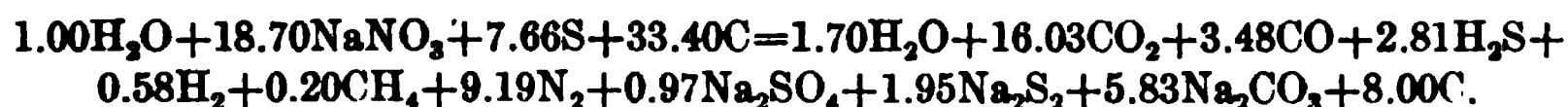
By the calorimeter it is found that 789.4 calories per gram are evolved (water liquid).

Each gram of products contains 0.0136 gram of H_2O, the correction for which (from liquid to gas) is:

$$\frac{10900 \times 0.0136}{18} = 8.23 \text{ calories per gram of products}$$

Applying this correction gives $789.4 - 8.23 = 781.2$ calories $=$ evolution of heat per gram of products (water gaseous), and for the 2,254 grams of material in the reaction,

$$Q = 1,760,825 \text{ calories}$$

then

$$t = \frac{-464.749 + \sqrt{(464.749)^2 + 4 \times 0.12883 \times 1,760,825}}{2 \times 0.12883}$$

$$t = 2,310°$$

In the calculation (p. 42) Q was found from analysis to be 1,661,739 calories and $t = 2,215°$.

For the explosive calculated on pages 42 to 45, the following reaction is obtained.

$13.31 H_2O + 6.50 C_3H_5(NO_3)_3 + 1.00 Ba(NO_3)_2 + 5.66 C_{15}H_{22}O_{10} + 14.86 KNO_3 + 2.43 C_6H_{10}O_5$
$= 34.04 H_2O + 32.01 CO_2 + 61.54 CO + 49.36 H_2 + 16.80 N_2 + 9.71 CH_4 + 6.17 K_2CO_3 + 12.33 C$
$+ 2.52 KHCO_3 + 1.00 BaCO_3$
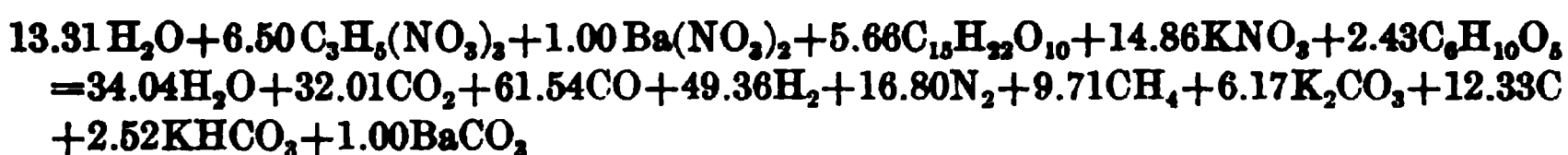
Heat evolved per gram, from the calorimeter reading, $= 570.7$ calories (H_2O liquid).

$$1 \text{ gram products} = 0.1035 \text{ gram } H_2O$$

Correction for H_2O liquid to H_2O gaseous equals

$$\frac{10900 \times 0.1035}{18} = 62.67 \text{ calories per gram}$$

Then

$$570.7 - 62.67 = 508.03 \text{ calories evolved per gram of products (water gaseous)}$$

and for the 5,920 grams of material in the reaction,

$$Q = 3,007,537 \text{ calories}$$

and

$$t = \frac{-1,400.93 + \sqrt{(1,400.93)^2 + 4 \times 0.377885 \times 3,007,557}}{2 \times 0.377885}$$

$$t = 1,522°$$

The value of Q calculated from the analysis was 2,767,805 calories, and $t = 1,426°$ (p. 45).

The calorimeter test of the explosive calculated on page 47 furnishes still another example. In this case there was an evolution of 827.6 calories per gram (H_2O liquid); the reaction being:

$22.82 H_2O + 8.7 C_3H_5(NO_3)_3 + 72.84 NaNO_3 + 1.00 CaCO_3 + 3.45 MgCO_3 + 1.22 S + 1.87 C_{75}H_{60}$
$O_2N = 56.51 H_2O + 46.81 CO_2 + 55.07 CO + 21.65 H_2 + 4.03 CH_4 + 56.13 N_2 + 1.00 CaCO_3 +$
$3.46 MgCO_3 + 35.43 C + 1.22 Na_2S + 35.22 Na_2CO_3$.
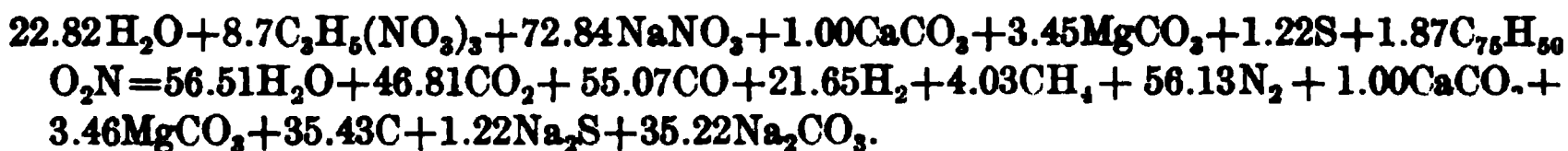
Hence

$$827.6 - \frac{10,900 \times 0.0935}{18} = 827.6 - 56.2 = 771.4 \text{ calories per gram } (H_2O \text{ gaseous}).$$

For the total material in the reaction (10,878 g.) $Q = 771.4 \times 10878 = 8,391,289$ calories.

Then

$$t=\frac{-2,524.934+\sqrt{(2,524.934)^2+4\times0.687582\times8,391,289}}{2\times0.687582}$$

$$t=2110°$$

By the calculation from analysis was found,

$$Q=8,322,270 \text{ calories}$$
$$t=2,098°.$$

PRACTICAL METHODS OF REDUCING THE FLAME TEMPERATURES OF EXPLOSIVES.

Among the methods which have been used for reducing the flame temperature of explosives, the following list seems to include all that are at present of importance:

(*a*) The addition of an excess of carbon, for the purpose of reducing the amount of carbon dioxide formed.

(*b*) The addition of free water.

(*c*) The addition of solids holding water of crystallization.

(*d*) The addition of inert materials, such as fine sand, clay, etc.

(*e*) The addition of easily volatile salts.

THE ADDITION OF AN EXCESS OF CARBON.

In regard to the first of the above methods, it has already been shown in the remarks on the thermochemistry of carbon monoxide and carbon dioxide (pp.19–21) that little reduction in temperature is brought about solely through the conversion of carbon dioxide to carbon monoxide, but that when this operation takes place in the presence of other materials having fairly high specific heats, a very decided reduction in temperature results. The low specific heat of carbon monoxide prevents a reduction in temperature by the conversion of carbon dioxide into carbon monoxide, but in all cases where other materials are produced (and in all commercial explosives other gases are formed with carbon dioxide and carbon monoxide), this reaction may result in pronounced lowering of temperature. The maximum temperature of explosion of nitroglycerin has already been shown to be 3,155° C. To show the manner in which the conversion of the carbon dioxide produced in the explosion of nitroglycerin into carbon monoxide would affect the maximum temperature of explosion, the maximum temperatures in the following reactions were calculated:

(1) $2C_3H_5(ONO_2)_3 = 5H_2O+3N_2+6CO_2+\frac{1}{2}O_2$

(2) $2C_3H_5(ONO_2)_3+ C=5H_2O+3N_2+6CO_2+CO$

(3) $2C_3H_5(ONO_2)_3+2C=5H_2O+3N_2+5CO_2+3CO$

(4) $2C_3H_5(ONO_2)_3+3C=5H_2O+3N_2+4CO_2+5CO$

(5) $2C_3H_5(ONO_2)_3+4C=5H_2O+3N_2+3CO_2+7CO$

(6) $2C_3H_5(ONO_2)_3+5C=5H_2O+3N_2+2CO_2+9CO$

(7) $2C_3H_5(ONO_2)_3+6C=5H_2O+3N_2+CO_2+11CO$

(8) $2C_3H_5(ONO_2)_3+7C=5H_2O+3N_2+13CO$
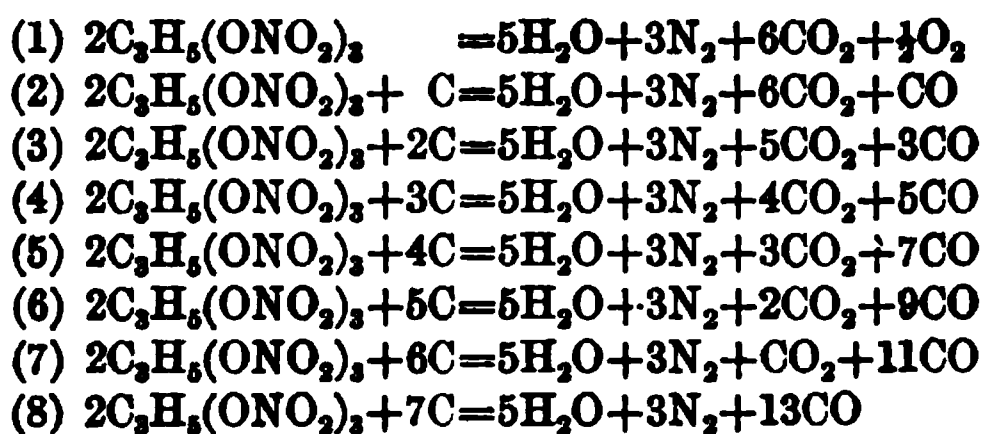
The values obtained in each case were as follows:

Effect of added carbon in lowering flame temperature of nitroglycerin.

	Total calories	Calories per gram	Calories per liter	Liters per gram	t°
Reaction 1	666,402	1,468	2,052	0.715	3,155
Reaction 2	692,775	1,486	2,062	.721	3,201
Reaction 3	651,220	1,362	1,817	.750	3,121
Reaction 4	609,665	1,244	1,601	.777	3,033
Reaction 5	568,110	1,131	1,409	.803	2,936
Reaction 6	526,555	1,024	1,237	.828	2,828
Reaction 7	485,000	922	1,082	.852	2,709
Reaction 8	443,445	824	942	.874	2,577

In the explosion of nitroglycerin no carbon monoxide is produced. All of the carbon present in the nitroglycerin is converted into carbon dioxide. By the addition of successive quantities of carbon the formation of this carbon dioxide is prevented, double the volume of carbon monoxide in each case resulting. Comparison of the maximum temperatures produced shows that the addition of the first gram-molecule of carbon gave an increase in temperature, the explosion of nitroglycerin alone reaching 3,155° C. and that of the mixture $2C_3H_5(NO_3)_3+C$, 3,201°. The reason for this is found in the free oxygen produced in the decomposition of nitroglycerin, this oxygen combining with the carbon to form carbon dioxide, and thus bringing about an increase in the temperature produced by the reaction. When the columns of figures are examined in detail, it will be seen that the calories evolved per liter of gas are more than twice as great in the case of nitroglycerin alone as when the nitroglycerin is mixed with 7C. The temperature, however, because of the low specific heat of carbon monoxide, does not undergo a corresponding change. The difference between the explosion temperature of pure nitroglycerin and that of nitroglycerin +7C is less than 600°.

When additional water is present during the reaction a much greater reduction in temperature is brought about, as will be seen from the following example:

$$2C_3H_5(NO_3)_3+7C+5H_2O=10H_2O+3N_2+13CO$$

Heats of formation of decomposition products.	Heats of formation of original constituents.
Calories.	Calories.
$10\times58,100=581,000$	$2\times98,900=197,800$
$13\times26,100=339,300$	$5\times69,000=345,000$
$^a26\times\ \ \ 545=\ \ 14,170$	
	$542,800$
$934,470$	

$$Q=934,470-542,800=391,670 \text{ calories.}$$

---

^{a} Compensation for 26 gram-molecules of gas.

HEAT CAPACITY OF DECOMPOSITION PRODUCTS.

$$c = a + bt$$

$$10H_2O = 10 \times 5.61 = 56.10 + 10 \times .0033t = 0.0330t$$
$$3N_2 + 13CO = 16 \times 4.80 = \underline{76.80} + 16 \times .0006t = \underline{.0096t}$$
$$\text{Total heat capacity, } c, = 132.90 + \qquad\qquad .0426t$$

Hence,

$$t = \frac{-132.90 + \sqrt{(132.90)^2 + 4 \times 0.0426 \times 391,670}}{2 \times .0426}$$

$$t = \frac{157.62}{0.0852}$$

$$t = 1,850°$$

Hence the addition of an excess of carbon to any explosive in the explosion of which considerable amounts of carbon dioxide are produced, in order to cause the formation of carbon monoxide in the place of carbon dioxide, is an efficient means of reducing the flame temperature, and the efficiency of the method is proportional to the specific heats of the products of combustion of the explosives.

THE ADDITION OF FREE WATER.

The high specific heat of water makes it a desirable constituent of the products of combustion of an explosive. At the temperature of explosion, water performs an important function in increasing the gaseous volume of the explosive. As the water is present in the explosive in a free condition, the number of calories that represent the change from liquid water to gaseous water must be absorbed from the heat produced by the explosive, and in this way a further reduction in the temperature is brought about. Water, up to 1.5 or 2 per cent, is present in nearly all explosives as an accidental impurity due to the hygroscopicity of certain constituents, particularly sodium nitrate and wood pulp. Water, up to 10 or 12 per cent, is found in certain classes of explosives intended for use in the presence of explosive-gas mixtures. In these classes the excess of water over the 1.5 to 2 per cent normally present, represents an intentional addition of water for the purpose of reducing flame temperature. The amount of water which can be added during manufacture to any explosive mixture depends upon the absorptive capacity and the consistency of the finished explosive.

The composition of an explosive may be such as to make inadvisable the addition of the amount of free water which calculations show to be necessary to properly reduce the flame temperature. In cases of this sort, the use of water chemically combined as water of crystallization may be resorted to, since water in chemical combination in crystals can be added to an explosive mixture in greater quantities than would ever be advisable with free water. The following considerations will show the amount of energy that is required to

change free water in an explosive to gas at the temperature of explosion:

The conversion of liquid water at zero to gaseous water at zero requires the absorption of 10,900 calories for each gram-molecule. If the reaction occurs under constant conditions of volume, as is usually assumed in all cases of explosive decomposition, the value will be 545 calories less, or 10,355 calories.

The mean molecular heat of gaseous water is

$$c = 5.61 + 0.0033t$$

Since $t = \dfrac{Q}{c}$ and $c = a + bt$, the law expressing the amount of heat required to raise a gas to a given temperature, t, under conditions of constant volume, is

$$Q = at + bt^2.$$

By the aid of these data the number of calories that will be absorbed in any explosive by the addition of a given amount of water, may be calculated, and the number of calories required to raise the temperature of a given amount of water vapor may also be determined. If the raising of 1 gram-molecule (18 grams) of liquid water from 0° to 2,000° C. be taken as an example, the figures will be as follows:

The conversion of 1 gram-molecule of liquid water to gaseous water, at constant volume, requires 10,355 calories. Therefore Q, the quantity of heat required to convert 1 gram-molecule of liquid water at 0° C. to gaseous water at 2,000° C., will be:

$$10,355 \text{ calories} + (5.61 \times 2,000 + 0.033 \times 4,000,000) = 34,775 \text{ calories}$$

As this is for 18 grams of water, it will be seen that for each gram of liquid water present in any explosive, 1,932 calories will be required to raise the temperature of this water from 0° to 2,000° C. By calculating in this way, the approximate amount of water required in an explosive to reduce its flame temperature to a safe limit may be ascertained.

THE ADDITION OF SOLIDS HOLDING WATER OF CRYSTALLIZATION.

Free water affects the consistency of explosives. If present in considerable quantity with nitroglycerine, it causes the latter to exude from the cartridges of the explosive. Water combined as water of crystallization does not have either of these disadvantages. Moreover, it possesses an advantage in the fact that heat is absorbed in breaking the union between the salt and the water, and in this way an additional absorption of heat is brought about. An example of salts holding water of crystallization that are suitable for use in explosives is magnesium sulphate, $MgSO_4 \cdot 7H_2O$.

This material, commercially known as Epsom salt, is a white crystalline solid, neither markedly efflorescent nor deliquescent under ordinary atmospheric conditions. Calculation from its formula shows that it contains 51.22 per cent water. When 1 gram-molecule of magnesium sulphate unites with 7 molecules of water to form Epsom salt, 24,080 calories are evolved. Therefore, in the breaking up of the salt, allowance must be made for this amount of heat, as well as for that absorbed in converting the liquid water to gaseous water and in raising the temperature of the water and the solid residue to the temperature of explosion. The total heat absorbed for 1 gram-molecule of the Epsom salt is therefore:

Calories.

Heat of hydration of $MgSO_4 \cdot 7H_2O$ .... = 24,080
Heat of vaporization of $7H_2O$, at constant volume ($7 \times 10,335$). = 72,485
Heat required to raise $7H_2O$ to 2,000° ($Q = at + bt^2$) .... = 170,940
Heat required to raise $MgSO_4$ to 2,000° ($S_{m(0^\circ - t^\circ)} = S_0 + S_0$
$\times .0002t$) .... = 75,600

343,105

As this result is for 1 gram-molecule, or 246 grams, of Epsom salt, it follows that the quantity of heat absorbed by 1 gram will be 1,394 calories.

The following table shows for a number of crystalline salts the percentage of water, the heat required to raise the temperature of 1 gram-molecule of the material from 0° to 2,000° C., the heat required to raise 1 gram, and the volume of water vapor at 2,000° C. (constant pressure), resulting from 1 gram of the crystallized salt:

Cooling properties of several crystalline salts.

Formula.	Per cent of H_2O.	Calories per gram-molecule (0°–2,000° C.).	Calories per gram (0°–2,000° C.).	Volume of H_2O in liters per gram at 2,000° C.
$Al_2K_2(SO_4)_4 \cdot 24H_2O$	45.57	1,229,232	1,297	4.722
$Al_2(SO_4)_3 \cdot 18H_2O$	48.81	922,950	1,396	5.057
$ZnSO_4 \cdot 7H_2O$	43.90	344,654	1,200	4.548
$MgSO_4 \cdot 7H_2O$	51.22	343,105	1,394	5.307
$Na_2SO_4 \cdot 10H_2O$	55.90	458,895	1,425	5.792
$Na_2CO_3 \cdot 10H_2O$	62.93	441,063	1,542	6.520
$(NH_4)_2C_2O_4 \cdot H_2O$	12.67	200,070	1,409	1.313

THE ADDITION OF INERT MATERIALS.

Fire clay, sand, and other materials of a like nature are sometimes added to explosive material, in which they act as a filler or substance to give weight and also exercise an influence in regard to the reduction of flame temperature. From a critical study of the properties of these materials it does not seem that decided advantages are

gained by their use for the purpose of lowering the flame temperature, since the result achieved is certainly far less than is the case when either salts holding water of crystallization or easily volatile substances are employed. Some data as to this low efficiency in regard to the reduction of flame temperature may be gained by taking a typical substance, silicon dioxide, and calculating the number of calories required to raise this material to the temperature of 2,000° C.

$$S_o \text{ for } SiO_2 = 0.191.$$

From this it appears that only 534.8 calories are required to raise the temperature of 1 gram of silicon dioxide from 0° to 2,000° C. When this value is compared with 1,394 calories required, through the same temperature range, for magnesium sulphate, or with 1,200 calories for zinc sulphate, etc., it will be seen that a small quantity of one of these hydrated salts will give all the advantages obtained by the use of a larger quantity of an inert substance, while at the same time the gaseous matter produced from the hydrated salt will assist the explosive action of the material.

THE ADDITION OF EASILY VOLATILE SALTS.

Any substance, solid at ordinary temperatures and completely gaseous at the temperature reached during the reaction of an explosive, forms a means of reducing the maximum flame temperature produced by explosives. Heat is absorbed in raising the solid material to its temperature of fusion. Heat is also absorbed in the process of fusion and in heating the fused material to the temperature of volatilization. A further quantity of heat is absorbed in the volatilization of the material and the heating of the gases thus produced.

It is unfortunate that thermochemical data regarding the temperature of fusion and latent heats of volatilization of common substances are as yet so incomplete. Of the substances that might possibly be used in explosives for the purpose mentioned no note whatever is made in any of the tables so far found of thermochemical data in regard to their latent heats of volatilization, and in only one or two cases were estimates found in regard to the temperatures at which these changes occur. In the case of sodium chloride, a material that has been used with considerable success in the past few years as a component of explosive mixtures and is to-day the volatile salt most widely used for reducing the flame temperature of explosives, no references to either the latent heat of fusion or the latent heat of volatilization have been found in the pertinent literature. Therefore complete calculations of explosives involving sodium chloride can not be made with great accuracy.

As an example of the effects produced by relatively small additions of sodium chloride, an explosive of the following composition may be taken:

	Per cent.
Nitroglycerin	25. 0
Sodium nitrate	30. 5
Wood meal	39. 5
Potassium bichromate	5. 0
	100. 0

The charge limit of this explosive when tested in coal dust and air was found to be 150 grams. The composition of the explosive was then altered by the addition of sodium chloride, this material being used in place of potassium bichromate in the powder first mentioned. The composition of the new explosive was:

	Per cent.
Nitrogylcerin	25. 0
Sodium nitrate	30. 0
Wood meal	38. 0
Sodium chloride	7. 0
	100. 0

The charge limit of this explosive was found to be more than four times as great as that of the first explosive mentioned, and charges up to 635 grams were repeatedly fired into coal dust mixtures without causing ignition.

Sodium chloride has been added to a number of explosives, and the results have been in general to effect an increase in the charge limit and a lowering of the flame temperature.

In these calculations the influence of different compounds has been considered. only in relation to the thermochemical influence that every material will have upon the explosive mixture. Remembering the effects which some of these materials have when mixed with other ingredients used in explosives, one sees that some of these compounds which seem very advantageous when their thermochemical properties alone are considered can not be mixed with other substances commonly used in explosives. For example, crystals of sodium sulphate have 10 molecules of water of crystallization and 55.9 per cent of the weight of the crystallized substance is water. This substance might seem to be a desirable one to add to explosives for the purpose of introducing water of crystallization, and its cheapness might seem to make it particularly desirable. But sodium sulphate is an efflorescent salt, that is, one that gives off its water of crystallization with great readiness. Were this substance to be used as a constituent of an explosive containing ammonium nitrate, sodium nitrate, or other deliquescent material,

the crystals of sodium sulphate would gradually lose most of their moisture, and the deliquescent salts would absorb this moisture and become wet. It is accordingly evident that in the preparation of an explosive no efflorescent salts should be used if any deliquescent material is to be used in the composition of that particular explosive.

In the class of incompatibles, as substances are named that can not be mixed together without chemical action, are acid salts and nitroglycerin. Nitroglycerin becomes unstable in the presence of free acid, and any substance that is itself acid or which may become acid should not be mixed with nitrogylcerin nor added to explosives containing nitroglycerin. A nitroglycerin explosive containing a substance that might slowly develop acidity would undoubtedly, in the course of time, become unsafe through the gradual decomposition of the nitroglycerin. The formation of nitrous fumes increases the rapidity of decomposition of nitroglycerin and brings about conditions that may very readily result in an explosion.

Ammonium nitrate and potassium chlorate should not be used together in explosives. Although a mixture of these two materials is not dangerous as long as it is thoroughly dry, yet in the presence of moisture, changes occur that lead to the evolution of chloric acid and other decomposition products. Explosives containing potassium chlorate and ammonium nitrate have been found to be spontaneously inflammable, and several accidents have resulted from their use.

A complete list of incompatibles can not be given, but the general rule is that no substances, which, either dry or in the presence of a small amount of water, can react with one another at ordinary temperatures, ought to be used together in an explosive mixture. Substances that do not appear to react under ordinary conditions show evidences of chemical action in the presence of small amounts of moisture, and as it is never certain that an explosive mixture can be kept fully protected, compounds that show such a reaction should be carefully avoided.

HEATS OF FORMATION.

If no direct determinations have been made of the heat of formation of a combustible organic body, a very close approximation to the true value may be reached by calculation from the known heat of combustion of the material. By complete combustion the substance is resolved into carbon dioxide, nitrogen, water vapor, etc. It is evident that the heat of formation of the body from its elements will be the difference between the sum of the heats of formation of the products resulting from its complete combustion, and the heat of combustion of the material itself. As a simple example of this

method of calculation methane may be taken. Methane, burning to H_2O and CO_2, according to the reaction

$$CH_4+2O_2=2H_2O+CO_2,$$
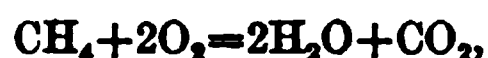
produces 13,343 calories per gram of methane.[a] Accordingly, the heat of combustion of 1 gram-molecule of methane will be $16\times13,343$ calories, or 213,488 calories. The heat of formation of 1 gram-molecule of CO_2 is 94,300, and the heat of formation of 2 gram-molecules of water is $2\times69,000$ calories (the water being liquid). The heat of formation of methane is the difference between 213,488 calories and $94,300+2\times69,000$, which is 18,812 calories.

Tables of heats of formation give 18,900 calories (Berthelot) as the heat of formation of methane, a value that is in substantial accord with the figure just deduced.

If the heat of formation of an organic body is known, but the heats of formation of its nitro derivatives or its organic nitrates have not been determined, the rule given by Berthelot is a convenient one for determining these values. He found that the action of nitric acid upon an organic body, with the entrance of the NO_2 group, evolved about 36,500 calories. As all the other products of reaction have constant heats of formation, this change may be expressed in an equation as follows:

$$C_aH_bO_c+nHNO_3=C_aH_{b-n}O_c\,(NO_2)_n+nH_2O+n36,500 \text{ calories}$$

As the heat of formation of nitric acid is 41,500 calories, and that of liquid water 69,000 calories, the equation should be so written as to state that the heat of formation of the original organic body plus 41,500 calories, equals the heat of formation of the nitro body, plus 69,000 calories, minus 36,500 calories.

Then
$$x+41,500 \text{ calories}=x+y+69,000 \text{ calories}-36,500 \text{ calories}$$

Eliminating x gives:
$$y=9,000 \text{ calories}$$

This indicates that 9,000 calories are evolved when one NO_2 group is introduced into an organic body. This fact may be expressed as a general rule covering organic bodies, as follows:

$$L=K+n\times9,000 \text{ calories}$$

where K is the heat of formation of the organic body, L is the heat or formation of the nitro-substitution body, and n is the number of nitro groups introduced.

In a similar way the heat of formation of an organic nitrate may be determined when the heat of formation of the corresponding

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simple body is known, and this may be expressed in general as follows:

$$L = Kn \times 22,400 \text{ calories}$$

where K is the heat of formation of any organic body, L is the heat of formation of its nitrate, and n is the number of nitrate groups that have been introduced.

In both of the cases above-mentioned it should be remembered that the physical state of the nitrate or nitro body must be the same as that of the original organic body, since the reactions take account only of the heat evolved in the chemical changes that take place upon the conversion of the original body into the final body. No account is taken of any change of state that occurs in the meantime, as, for example, a liquid organic body forming a solid nitro body.

As an example of the calculation of the heat of formation of a nitro body, the following may be taken:

The heat of formation of benzene (C_6H_6) was found to be $-4,100$ calories (Berthelot). By the rule just given the heat of formation of mono-nitrobenzene should be $-4,100$ calories $+9,000$ calories $= 4,900$ calories. A direct determination of the heat of formation of mono-nitrobenzene gave the value 5,100 calories (Berthelot). The theoretical calculation agrees within 200 calories with the value determined by experiment.

TABLES OF USE IN THERMOCHEMICAL CALCULATIONS.

The following tables contain data of value to the explosives chemist.

TABLE 1.—*Atomic weights, expressed in round numbers, of the elements likely to be met with in the manufacture of explosives.*

Element.	Symbol.	Atomic weight.	Element.	Symbol.	Atomic weight.
Aluminum	Al	27	Magnesium	Mg	24
Antimony	Sb	120	Manganese	Mn	55
Arsenic	As	75	Mercury	Hg	200
Barium	Ba	137	Nitrogen	N	14
Calcium	Ca	40	Oxygen	O	16
Carbon	C	12	Phosphorus	P	31
Chlorine	Cl	35.5	Potassium	K	39
Fluorine	F	19	Silicon	Si	28
Hydrogen	H	1	Sodium	Na	23
Iodine	I	127	Strontium	Sr	88
Iron	Fe	56	Sulphur	S	32
Lead	Pb	207	Tin	Sn	119
Lithium	Li	7	Zinc	Zn	65

TABLE 2.—*Weight of 1 liter of certain gases at 0° C. and 760 mm.*[a]

Substance.	Formula.	Weight.	Substance.	Formula.	Weight.
		Grams.			*Grams.*
Carbon dioxide	CO₂	1.965	Methane	CH₄	0.7150
Oxygen	O₂	1.429	Hydrogen sulphide	H₂S	1.522
Nitrogen	N₂	1.254	Ammonia	NH₃	.7615
Carbon monoxide	CO	1.251	Nitric oxide	NO	1.3417
Hydrogen	H₂	.0895			

a Hempel, Walther: Methods of Gas Analysis.

TABLE 3.—*Heats of hydration of some common crystalline salts.*

Substance.	Reaction.	Formula.	Calories.	Authority.
Zinc sulphate	$ZnSO_4+7H_2O$	$ZnSO_4\cdot7H_2O$	22,690	Thomsen.
Magnesium sulphate	$MgSO_4+7H_2O$	$MgSO_4\cdot7H_2O$	24,080	Do.
Sodium sulphate	$Na_2SO_4+10H_2O$	$Na_2SO_4\cdot10H_2O$	19,220	Do.
Sodium carbonate	$Na_2CO_3+10H_2O$	$Na_2CO_3\cdot10H_2O$	21,800	Do.
Ammonium oxalate	$(NH_4)_2C_2O_4+H_2O$	$(NH_4)_2C_2O_4\cdot H_2O$	3,500	Berthelot.
Aluminum sulphate	$Al_2(SO_4)_3+18H_2O$	$Al_2(SO_4)_3\cdot18H_2O$		
Potassium alum	$K_2Al_2(SO_4)_4+24H_2O$	$K_2Al_2(SO_4)_4\cdot24H_2O$		

TABLE 4.—*Molecular heats of gases, at constant volume, concerned in the thermochemical calculations of explosives.*

Substance.	Formula.	Specific heat of gas.	Substance.	Formula.	Specific heat of gas.
Carbon dioxide [a]	CO_2	$6.26+0.0037t$	Hydrogen [a]	H_2	$4.80+0.0006t$
Sulphur dioxide [a]	SO_2	$6.26+ .0037t$	Methane	CH_4	$7.10+ .0005t$
Water vapor [a]	H_2O	$5.61+ .0033t$	Ammonia	NH_3	$6.70+ .0005t$
Nitrogen [a]	N_2	$4.80+ .0006t$	Hydrogen sulphide	H_2S	$6.30+ .0005t$
Carbon monoxide [a]	CO	$4.80+ .0006t$	Nitric oxide	NO	$4.80+ .0006t$
Oxygen [a]	O_2	$4.80+ .0006t$			

[a] Mallard and LeChatelier, Compt. Rendus, vol. 93, 1881, p. 1014.

TABLE 5.—*Specific heats of solids found in explosion reactions.*

Substance.	Formula.	Temperature.	Specific heat.	Authority.
		°C.		
Aluminum oxide	Al_2O_3	0–100	0.1827	Nilson.
Ammonium chloride (crystallized)	NH_4Cl	15– 45	.373	Kopp.
Barium carbonate	$BaCO_3$	11– 99	.110	Regnault.
Barium chloride (fused)	$BaCl_2$	16– 47	.090	Kopp.
Calcium carbonate (marble)	$CaCO_3$	0	.2028	Webber.
Carbon	C		.533	(a)
Chromic oxide	Cr_2O_3	21– 52	.177	Kopp.
Dolomite	$CaMg(CO_3)_2$	18– 47	.206	Do.
Magnesium carbonate	$MgCO_3$		.206	(b)
Magnetite	Fe_3O_4	24– 99	.1678	Regnault.
Magnesium sulphate	$MgSO_4$	25–100	.225	Pape.
Potassium bicarbonate	$KHCO_3$		.206	(c)
Potassium bisulphate (crystallized)	$KHSO_4$	19– 51	.244	Kopp.
Potassium carbonate (fused)	K_2CO_3	17– 47	.206	Do.
Potassium chloride (fused)	KCl	13– 47	.171	Do.
Potassium sulphate (crystallized)	K_2SO_4	13– 45	.196	Do.
Potassium sulphate (fused)	K_2SO_4	15– 98	.190	Regnault.
Potassium sulphide	K_2S		.1615	Berthelot.
Pyrolusite	MnO_2	17– 48	.159	Kopp.
Quartz	SiO_2	20– 50	.186	Do.
Sodium bicarbonate (fused)	$NaHCO_3$		.246	(d)
Sodium carbonate (fused)	Na_2CO_3	18– 48	.246	Kopp.
Sodium chloride (fused)	$NaCl$	13– 46	.213	Do.
Sodium sulphate (crystallized)	Na_2SO_4	28– 57	.2293	Schüller.
Sodium sulphate (fused)	Na_2SO_4	17– 98	.2312	Regnault.
Sodium sulphide	Na_2S		.2436	Gody.
Zinc oxide (ignited)	ZnO	17– 98	.1248	Regnault.
Zinc sulphate	$ZnSO_4$	22–100	.174	Pape.

a Assumed to be $\frac{6.4}{12}$—0.533.

b Assumed to have the same value as dolomite.

c Assumed to have the same value as potassium carbonate.

d Assumed to have the same value as sodium carbonate.

TABLE 6.—*Heats of formation of some substances occurring in explosion reactions.*

[The components and products are considered in their actual condition at 15° C. Carbon is considered as crystallized.]

Substance.	Components.		Products.	Heat of formation.	Authority.
				Calories	
Aluminum sulphate........	Al	....	$Al_2(SO_4)_3 + Aq$....	879,700	Berthelot.
Ammonia.................	N	....	NH_3...	11,900	Thomsen.
Ammonium chloride........	N	....	NH_4Cl...............	75,800	Do.
Ammonium nitrate........	N	....	NH_4NO_3....	86,050	Do.
Ammonium oxalate.......	N	.. .	$(NH_4)_2C_2O_4$.........	270,100	Berthelot.
Ammonium sulphate.......	N	....	$(NH_4)_2SO_4$..........	281,900	Thomsen.
Barium carbonate..........	B	....	$BaCO_3$(amorphous)...	285,600	Do.
Barium chloride.......	B	.. ...	$BaCl_2$.................	197,100	Berthelot.
Barium nitrate............	B	....	$Ba(NO_3)_2$...........	228,400	Thomsen.
Calcium carbonate....... ..	Ca	.. ..	$CaCO_3$...............	270,400	Do.
Carbon dioxide.............	C-	....	CO_2...	94,300	Berthelot.
Carbon monoxide........ ..	C-	....	CO..................	26,100	Do.
Cellulose......	$C_6 + H_{10} + O_5$........		$C_6H_{10}O_5$............	230,400	Do.
Dinitronaphthalene...... ..	$C_{10} + H_6 + N_2 + O_4$.......		$C_{10}H_6(NO_2)_2$........	−4,800	Calculated.
Ferric oxide........	$Fe_2 + O_3$...............		$Fe_2O_3 \begin{cases} 400° C..... \\ 1,000° C..... \end{cases}$ ..	195,600 / 194,400	}LeChatelier.
Hydrogen sulphide....	H	... .	H_2S.................	2,700	Thomsen.
Magnesium carbonate......	M	....	$MgCO_3$(pptd.).........	266,600	Berthelot.
Magnesium sulphate.......	M	.. ..	$MgSO_4$..............	302,300	Thomsen.
Manganese dioxide.	M	....	MnO_2.............	126,100	LeChatelier.
Methane..................	C	......	CH_4.....	18,900	Berthelot.
Nitric oxide......	N	... .	NO.... ...	−21,600	Thomsen.
Nitrobenzene.......... ...	C	$+O_3$......	$C_6H_5NO_2$............	−4,100	Berthelot.
Nitroglycerin.....	C	$+O_4$......	$C_3H_5(NO_3)_3$.........	98,900	Do.
Nitronaphthalene...	C	$+O_2$.... .	$C_{10}H_7NO_2$..........	−13,800	Calculated.
Nitrotoluene......	C	$+O_2$........	$C_7H_7NO_2$........ ..	11,300	Do.
Paraffin.....	C	....	$C_{24}H_{50}$........	a 270,200	Do.
Potassium bicarbonate.. ..	K	O_3... .	$KHCO_3$.............	238,300	Berthelot.
Potassium bisulphate... ..	K	O_4.... ...	$KHSO_4$.............	277,100	Thomsen.
Potassium carbonate.... ..	K	... ..	K_2CO_3.............	261,100	Do.
Potassium chlorate... . .	K	....	$KClO_3$........	95,800	Do.
Potassium chloride... .	K	.. ..	KCl..	105,600	Do.
Potassium bichromate.....	K	....	$K_2Cr_2O_7$.............	15,000	Berthelot.
Potassium nitrate...	K	.. ..	KNO_3............	119,500	Thomsen.
Potassium perchlorate.....	K	....	$KClO_4$.............	112,500	Berthelot.
Potassium permanganate..	K	.. .. ..	$KMnO_4$....	194,300	Thomsen.
Potassium sulphate... ..	K	....	K_2SO_4........	344,600	Do.
Potassium sulphide..... ...	K	....	K_2S...	103,500	Sabatier
Sodium bicarbonate... ..	N	....	$NaHCO_3$..	229,300	Thomsen.
Sodium carbonate..........	N	....	Na_2CO_3...........	272,600	Do.
Sodium chlorate....... .	N	....	$NaClO_3$.............	86,700	Do.
Sodium chloride....	N	. ...	$NaCl$..	97,700	Do.
Sodium nitrate............	N	..... .	$NaNO_3$....	111,250	Do.
Sodium perchlorate..... ..	N	....	$NaClO_4$............	100,300	Berthelot.
Sodium sulphate............	N	....	Na_2SO_4......	328,600	Thomsen.
Sodium sulphide....... .	N	....	Na_2S	88,200	Sabatier.
Starch...................	C	....	$C_6H_{10}O_5$............	225,900	Berthelot.
Sulphur dioxide.... ...	S	....	SO_2..............	71,100	Thomsen.
Trinitronaphthalene......	C	$+O_6$......	$C_{10}H_5(NO_3)_3$...........	4,200	Calculated.
Water....................	H	....	H_2O (gaseous).........	58,100	Berthelot.
Do......................	H	.. ..	H_2O (liquid)..........	69,000	Do.
Wood pulp.................	C	....	$C_{18}H_{20}O_{10}$..............	a 463,350	Calculated.
Zinc oxide.................	Z	.. ..	ZnO..................	85,000	Thomsen.

a Calculated from heat of combustion.

CHAPTER III.

CHARACTERISTICS OF THE NATURAL GAS USED AT PITTSBURGH.

By George A. Burrell.

INTRODUCTION.

In planning the work at the Pittsburgh station it was decided to use the natural gas supply of the city for forming the mixtures of gas and air used in the testing galleries. In order to ascertain the composition of this gas, and the extent to which the composition was liable to vary, the gas was analyzed every day for about two weeks. At the end of this period the results obtained had established the fact that the composition of the gas varied only little from week to week, and thereafter analyses were made weekly.

METHODS OF ANALYSES.

Tests for carbon dioxide, oxygen, hydrogen sulphide, olefine hydrocarbons, and carbon monoxide were occasionally made, using large amounts of the gas, but the analyses given were made by a eudiometric method, which followed in general the scheme of Hempel.[a] Since the completion of the analyses referred to in this bulletin apparatus has been devised that is superior in some respects to the Hempel apparatus for the analysis of natural gas. This apparatus will be described in a forthcoming publication of the Bureau of Mines. The burette used was graduated in tenths of 1 cubic centimeter. It was water-jacketed, and had a compensating device.[b] Because of the latter, small differences in room temperature during the progress of analyses could be disregarded. This device also afforded a quite precise means of making adjustments before the taking of burette readings. Mercury was used in the measuring burette and in the combustion pipette. With the apparatus used an accuracy greater than 0.1 per cent could hardly be attained; consequently when a constituent was reported absent assumption was made that its presence could not be detected in amount greater than this figure.

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a Hempel, Walther: Methods of Gas Analysis. English translation by L. M. Dennis, 1910.
b Idem, p. 61.

Discovery was early made that the accurate determination of the constituents present in the natural gas offered difficulties of no small moment. Those constituents absorbable by solutions were either absent or present in such small quantities that their estimation by ordinary eudiometric methods required strict attention to detail in handling the apparatus, and the large amount of combustible gas present required for its determination the use of a large percentage of the residual gas left after the absorption solutions had been used. Experience showed that through poor manipulation and misuse of the solutions one might easily report several tenths of 1 per cent or more of a gas that was either present in much smaller amounts than this or which was entirely absent.

CARBON DIOXIDE.

Carbon dioxide is found almost everywhere and its presence in natural gas should cause no surprise, yet the natural gas used at Pittsburgh contains only small quantities of it, usually such amounts that its presence can not be detected with the apparatus used. Passing the gas through lime water, however, shows that carbon dioxide is present.

OXYGEN.

Tests with alkaline pyrogallate solution showed the occasional presence of traces of oxygen in the samples analyzed. This oxygen was not necessarily present in the gas at the wells, but was probably introduced into the gas as it traversed the pipe lines. The quantities occasionally found were so small, however, as to lie within the accuracy of making the determinations.

OLEFINE HYDROCARBONS.

Search was made for olefine hydrocarbons by means of fuming sulphuric acid and a saturated solution of bromine water. The practice was to pass the gas into the acid and immediately withdraw it. The acid fumes were then removed by washing the gas with a solution of caustic potash. On some samples several tenths of 1 per cent reduction in volume of the sample followed. Bromine was tried several times in those cases where the sulphuric acid gave a positive result and caused one-half as much reduction in volume of the gas as that caused by the acid. Later, qualitative tests were conducted by passing the gas through a dilute solution of palladium chloride,[a] but no reduction of the salt followed. This reaction is extremely delicate. In the presence of olefine hydrocarbons, carbon monoxide, or hydrogen sulphide, palladium is precipitated and appears as a

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[a] F. C. Phillips: Researches upon the phenomena of oxidation and chemical properties of gas. Am. Chem. Jour., vol. 16, No. 4, p. 267.

dark cast or as suspended particles throughout the liquid. An examination of certain natural gases from southern California that were heavily impregnated with higher members of the paraffin series, showed that the solution of these higher paraffins in fuming sulphuric acid is very marked, and that tests for paraffin hydrocarbons in natural gas by the use of fuming sulphuric acid may be misleading. R. A. Worstall[a] has also made the latter observation.

CARBON MONOXIDE.

A solution of cuprous chloride did not prove satisfactory in testing natural gas containing higher members of the paraffin series for carbon monoxide, because it exerted a slight solvent action upon those members; consequently qualitative tests were made by using dilute solutions of blood or palladium chloride. Spectroscopic examinations were also made, but carbon monoxide was in no case detected. Experimental work on known amounts of carbon monoxide showed that the presence of 0.1 per cent of carbon monoxide could be detected by the means employed. The method consisted in passing 200 cubic centimeters of the natural gas at the rate of 10 cubic centimeters per minute through a dilute blood solution (in which 1 volume of blood was diluted 225 times with water) in test tubes 6 inches long and 0.75 inch wide. The pink color characteristic of carbon monoxide-haemoglobin was not imparted to the blood solution.

HYDROGEN SULPHIDE.

Tests for hydrogen sulphide were made by means of iodine and starch, also by passing the gas through a solution of lead acetate for several hours. No hydrogen sulphide was found.

HYDROGEN.

Palladium asbestos heated to 100° C. was used in testing for hydrogen. A contraction in volume was never obtained by passing the gas over this substance. The working qualities of the palladium asbestos were checked by means of gas mixtures containing known quantities of hydrogen.

PARAFFIN HYDROCARBONS.

The slow-combustion method was used for the determination of the paraffin hydrocarbons, as follows: Fifty cubic centimeters of the gas residue were introduced into a Dennis-Winkler slow-combustion pipette and the platinum spiral was heated to a bright red; 150 cubic centimeters of oxygen were then added at the rate of 10 to 15 cubic centimeters per minute. By this procedure the gas burned quietly

a Jour. Am. Chem. Soc., vol. 21, 1899, p. 245, and vol. 20, 1898, p. 264.

as fast as it entered the pipette and an explosion consequent on an accumulation of gas and air was prevented. An air blast was used to expedite the cooling of the pipette after combustion; it proved efficient as it reduced the time required for combustion and cooling to about six minutes. An analysis of natural gas follows which shows the method of procedure and calculation.

Analysis of natural gas.

	Burette reading.	Per cent.		Burette reading.	Per cent.
	Cubic centimeters.			*Cubic centimeters.*	
Volume of sample taken.......	100.0	....	Volume after carbon dioxide		....
Carbon dioxide....	99.9	0.1	absorption................	40.1	....
Oxygen....................	99.9	.0	Carbon dioxide...........	57.4	....
Paraffins by combustion—			Partial methane..........	41.0	....
Total residue..........	99.9	....	Partial ethane...........	8.2	....
Portion taken.........	50.0	....	Total methane...........	....	82.0
Oxygen added........	150.0	....	Total ethane............	....	16.4
Total volume.........	200.0	....	Nitrogen...............	....	1.5
Volume after burning..	97.5	....			
Contraction..........	102.5	....			100.0

The paraffin hydrocarbons have the general formula C_nH_{2n+2}. The following list includes six of these hydrocarbons:

CH_4..Methane.
C_2H_6..Ethane.
C_3H_8..Propane.
C_4H_{10}..Butane.
C_5H_{12}..Pentane.
C_6H_{14}..Hexane.

The first four members are gases at ordinary temperatures.

Hexane is the main constituent of the gasoline obtained from the distillation of oils having paraffin bases. Gasoline obtained from natural gas in the oil fields contains lower members of the paraffin series than gasoline procured by refining petroleum. So volatile is some of the gasoline from natural gas that difficulty has been experienced in preventing considerable loss of the liquid by evaporation. Liquid butane has a boiling point of 1° C.,[a] consequently a rapid volatilization takes place at ordinary temperatures from natural gas gasoline containing butane.

It is believed that paraffins higher than ethane exist in traces only in the natural gas used at Pittsburgh. Because of the high rock pressure to which the gas is subjected in the earth, and the miles of pipe line traversed by some of the gas before it reaches Pittsburgh, paraffins higher than ethane are probably present in very small quantities in the gas as it enters the city. Because of the lack of a sufficient proportion of the higher paraffins, the manufacture of gasoline from the gas at Pittsburgh is not a commercial success.

a Watt's Dictionary of Chemistry, 1905, vol. 1, p. 638.

A test conducted by passing the gas very slowly for five hours through a glass tube 8 inches long and 0.5 inch wide, placed in a freezing mixture having a temperature of $-10°$ C., resulted in no visible condensation. This test does not show the entire absence of butane, but some condensation should have occurred were the gas present in quantity beyond that required to saturate the other gases with butane vapor at the temperature used. Propane in the liquid condition boils at $-17°$ C.[a]

The solubility of natural gas in absolute alcohol was tried by shaking 1 cubic centimeter of the latter with 100 cubic centimeters of natural gas in a Hempel explosion pipette over mercury. The alcohol dissolved 2.5 cubic centimeters of the gas.

The solubility of some of the paraffin hydrocarbons in alcohol is as follows:

1 volume of alcohol dissolves 0.523 volume of methane at 0° C.[b]
1 volume of alcohol dissolves 1.5 volumes of ethane.[c]
1 volume of alcohol dissolves 6.0 volumes of propane.[d]
1 volume of alcohol dissolves 18.0 volumes of butane.[e]

The relative solubilities of the individual paraffins as compared to the solubility of the natural gas in the alcohol indicates that the higher paraffins are not present in the latter mixture in large amounts.

No satisfactory method of calculating the members of the paraffin series in an unknown mixture of two or more of the latter is known. No absorbents are known that will qualitatively absorb in turn the different members and leave the others untouched. Consequently they are determined as a whole by combustion as stated before. In the typical example given, the combustion data, that is, the carbon dioxide formed and the contraction produced by the complete combustion of the natural gas, have been calculated to methane and ethane according to the following reactions:

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

$$C_2H_6 + 3\tfrac{1}{2}O_2 = 2CO_2 + 3H_2O$$
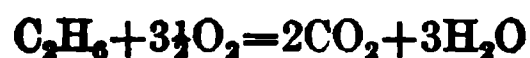
Let x = the quantity of methane, and let y = the quantity of ethane.

Then the carbon dioxide produced $= x + 2y$, and the contraction produced $= 2x + 2\tfrac{1}{2}y$.

The amounts of methane and ethane as determined by this procedure are not correct if a mixture of more than two paraffins is present, but the figure for total paraffins determined by this calculation is correct, regardless of the quantity or character of the individual

a Watt's Dictionary of Chemistry, 1907, vol. 4, p. 307.
b Watt's Dictionary of Chemistry, 1906, vol. 3, p. 251.
c Watt's Dictionary of Chemistry, 1906, vol. 2, p. 460.
d Watt's Dictionary of Chemistry, 1907, vol. 4, p. 307.
e Watt's Dictionary of Chemistry, 1906, vol. 1, p. 638.

paraffins present. This can be shown as follows: Propane and butane combine with oxygen according to the following reactions:

$$C_3H_8 + 5O_2 = 3CO_2 + 4H_2O$$

$$C_4H_{10} + 6\tfrac{1}{2}O_2 = 4CO_2 + 5H_2O$$
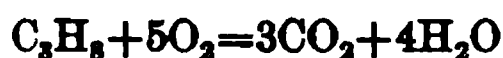
Let an assumption be made of a mixture of 100 volumes of paraffins divided as follows:

	Volumes.
CH_4	80
C_2H_6	15
C_3H_8	4
C_4H_{10}	1

This mixture with sufficient oxygen for complete combustion would produce 126 volumes of carbon dioxide and undergo a contraction in volume of 213 volumes. The combustion data if calculated as methane and ethane are equivalent to 74 volumes of methane and 26 volumes of ethane. The proportions are incorrect, but the amount of total paraffins is exact. The 74 volumes of methane and 26 volumes of ethane consume the same amount of oxygen upon burning as the 100 volumes of the mixture. In view of these facts it can be seen that the heating value of the natural gas used at Pittsburgh calculated on the assumption that methane and ethane only are present is correct. Let the following heating values be used:

Methane has a heating power of 1,065 British thermal units per cubic foot at 32° F. and 760 millimeters of mercury.

Ethane has a heating power of 1,861 British thermal units per cubic foot at 32° F. and 760 millimeters of mercury.[a]

According to the analyses on page 95, the natural gas has a heating value of 1,179 British thermal units per cubic foot at 32° F. and 760 millimeters of mercury. This figure has been verified by trial with a Junker calorimeter.

COLLECTION AND ANALYSIS OF GAS SAMPLES FROM THE TESTING GALLERY.

For a long time a value, called the methane equivalent, was determined daily. It is now determined biweekly. The methane equivalent is the volume of carbon dioxide that 100 cubic centimeters of the gas will produce on undergoing complete combustion and is equal to the carbon dioxide produced by the combustion of the methane and ethane.

Samples of the various mixtures of gas and air, collected over water in a suitable container by the engineer in charge of the gallery, were sent to the laboratory for analysis. Upon arrival at the laboratory a sample was transferred to a water-jacketed burette, measured, and

a Landolt-Bornstein, Physikalisch-chemische Tabellen, fifth edition, p. 425; from J. Thomsen, Thermochemische Untersuchungen, vol. 4, 1886.

passed into the slow combustion pipette. If the sample was an explosive mixture, enough air was added to make the mixture nonexplosive. After combustion the gas was drawn back into the burette, measured, and transferred to the pipette containing potassium hydroxide. The volume of carbon dioxide found was then divided by the methane equivalent and the result multiplied by 100 to obtain the percentage of natural gas in the sample. This figure was then multiplied by the percentage of the various constituents of the natural gas as determined by the analysis for that week, giving the percentages of methane, ethane, and nitrogen in the gas mixture.

At present in analyzing gas-air mixtures the contraction due to combustion only is determined. This figure is divided by the figure giving the contraction in centimeters produced by complete oxidation of 100 cubic centimeters of natural gas, to determine the amount of natural gas in the gas-air mixture. The calculation is continued as stated above.

To show that the method of collecting samples of the gas-air mixtures over water had no effect on the accuracy of the work, the two following sets of analyses are cited. The first set was made immediately upon taking the sample and the second set after the sample had stood over water for two days.

Analyses of gas-air mixtures.

Date analyzed.	Natural gas.		
	Sample 1.	Sample 2.	Sample 3.
	Per cent.	*Per cent.*	*Per cent.*
Sept. 9, 1909............................	4.15	4.29	4.29
Sept. 11, 1909...........................	4.10	4.27	4.27

Collecting samples over water was permissible because there were in the gas no constituents upon which water has an appreciable solvent action.

EXPLOSIBILITY OF GAS-AIR MIXTURES.

In order to interpret satisfactorily the results of the tests of explosives at the Pittsburgh station, the explosive characteristics of the gas-air mixtures used were investigated. Mixtures of combustible gases with air are explosive within certain definite limits. If, starting with the most explosive mixture, the proportion of air in the mixtures be gradually increased, the explosions become less and less violent until at last a mixture is obtained containing so small a percentage of gas that it can not be exploded. This is called the lower limit of explosion. Similarly, if the proportion of gas be gradually increased a mixture is finally obtained that is incapable of explosion. This is called the upper limit of explosion.

These limits for different gases appear to be determined largely by the quantity of air required for complete combustion. The explosion limits of the same mixture will vary somewhat with the size and shape of the vessel used, the method of ignition employed, and the temperature and pressure of the mixture. Hence it is practically impossible to define exact limits within which gas-air mixtures are explosive. If a spherical vessel be used, the limits are somewhat wider than those obtained by the use of a long, narrow one; also, if the mixture be ignited by a flame, especially if the flame be applied at the bottom of the vessel, the limits differ from those obtained when the mixture is ignited by an electric spark. The size of the spark also makes some difference.

The explosion limits[a] of the more common combustible gases, such as methane, hydrogen, and carbon monoxide, have been carefully investigated and values that agree fairly well have been determined by different chemists.

The higher homologues of the paraffin series, when in the gaseous state, have narrower explosion limits than the lower members. Methane, for instance, has a lower limit of 6 per cent gas and a higher limit of 13 per cent, while pentane (fifth in the series) has a lower limit of 2.4 per cent and a higher limit of 4.9 per cent. Because natural gas contains ethane one would expect its explosion limits to be somewhat narrower than those of methane. Experiments made at different times during the year showed that the limits for natural gas varied somewhat, even though the conditions under which the experiments were performed were nearly similar. The following results, obtained by using a Hempel explosion pipette, with mercury as the confining fluid, show this variation:

Explosion limits of mixtures of air and natural gas.

	Percentage of gas.	
	Low limit.	High limit.
Sample No. 1	4.8	....
Sample No. 2	5.0	12.4
Sample No. 3	5.3	11.8

As the gas did not change enough in composition to account for this variation, conditions in the experiments by which the limits were determined were probably responsible. In the case of the third sample, water instead of mercury was used in the burette in which the gas and air were measured, and the spark was more feeble than in the first and second cases. In addition, the values were determined under different weather conditions.

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[a] In this discussion of the explosion limits of a gas, the gas is assumed to be mixed with air unless a contrary statement is made.

COMPARISON OF EXPLOSION LIMITS OF VARIOUS GAS-AIR MIXTURES.

In determining the explosion limits of natural gas and air mixtures, the main essential has to do with a comparison with the explosion limits of other gases, principally with those of methane and, to a lesser degree, with those of coal gas. The last comparison is of consequence, because coal gas is used at the Woolwich testing gallery in England. Consequently the explosion limits for natural gas, methane, and coal gas were determined on the same day, with the same apparatus, and under conditions that were kept as nearly constant as possible. In common with the results obtained by other investigators, the lower limit of explosibility of gaseous mixtures was found to be somewhat below the limit at which the gas undergoes complete combustion. A mixture of natural gas and air can be exploded when it contains 5 per cent of gas, but complete combustion ensues only when the proportion of gas reaches to 5.4 per cent. For comparison the results obtained by other investigators are given below with those obtained at the Pittsburgh laboratory of the Bureau of Mines. The lowest point at which complete combustion was obtained was determined by measuring the carbon dioxide produced. It was found that in all cases the lower limit of explosibility coincided with the flash as seen by the eye. Where no flash could be seen, a measurable contraction in volume did not take place.

Explosion limits of gases.

Gas.	Remarks.	Low limit.	High limit.	Authority.
Natural gas used at Pittsburgh.	Incomplete combustion	5.0	} 12.0	Burrell.
Do.	Complete combustion	5.4		
Methane	Incomplete combustion	5.3	} 12.8	Do.
Do.	Complete combustion	5.7		
Do.	....do	6.1	12.8	Eitner.[a]
Do.	Fired from below	5.0	13.0	Clowes.[b]
Do.	Fired from above	{ 6.0	11.0	Do.
		6.0	13.0	Roszkowski.[c]
Coal gas.	Incomplete combustion	6.3	} 19.1	Burrell.
Do.	Complete combustion	7.9		
Do.	....do	7.9	19.1	Eitner.[a]
Do.	Fired from below	6.0	29.0	Clowes.[b]
Do.	Fired from above	{ 9.0	22.0	Do.
		7.0	22.6	Roszkowski.[c]
Ethylene	....do	4.0	22.0	Clowes.[b]
Pentane	Complete combustion	2.4	4.9	Eitner.[a]
Hydrogen	....do	9.45	66.4	Do.
Carbon monoxide	{ Fired from below	5.0	72.0	Clowes.[b]
	Complete combustion	16.5	74.95	Eitner.[a]
Do.	Fired from below	{ 13.0	75.0	Clowes.[b]
		14.3	74.6	Roszkowski.[c]
Acetylene	....do	3.0	82.0	Clowes.[b]

[a] Eitner P., Jour. Gasbel, vol. 45, pp. 21-24, 69-72, 90-93, 112-115. Abstract in Jour. Soc. Chem. Ind., vol. 21, 1902, p. 395.

[b] Clowes and Redwood, Detection and estimation of inflammable gases and vapor in air; 1896. Pp. 2 and 6.

[c] Kubierschky, K., Zeitschr. angew. Chem. 1901, vol. 6, pp. 129-132. Abstract in Jour. Soc. Chem. Ind., vol. 20, 1901, p. 345.

The experiments mentioned by Eitner were made over water in a Bunte explosion burette having a capacity of 110 cubic centimeters and an internal diameter of 19 millimeters. The ignitions were brought about by the spark of a powerful induction coil. Only those

combustions in which a contraction corresponding to the complete combustion of the gas was observed were accepted as explosions. The lower limits given by Eitner were determined when an open cylinder 62 millimeters in internal diameter was used, ignition being effected by applying the flame at the top of the vessel. They were as follows:

	Per cent.
Hydrogen	8. 5
Ethylene	3. 4
Methane	6. 3
Pentane	1. 3

Clowes's experiments were made in a glass cylinder 3 inches in internal diameter and closed at one end. Ignition was effected by firing the gas with a flame, both from above and below.

The coal gas mentioned in the above table of the explosion limits of gases had the following composition:

Composition of coal gas used in experiments.

Constituent gases.	Gas used by Eitner.	Gas used by Burrell.
	Per cent.	*Per cent.*
Hydrogen	50. 75	43. 0
Methane	34. 30	36. 5
Carbon monoxide	7. 05	10. 0
Illuminants	4. 25	6. 4
Carbon dioxide	1. 95	1. 6
Nitrogen	1. 70	2. 5

It was noted that the dividing line between an air and coal gas mixture that would not and one that did explode (at the lower limit) was not sharply defined. With 6.3 per cent of gas a reduction in volume of 0.3 cubic centimeters was recorded. From this point the explosion gradually increased in violence until the proportion of gas was 7.9 per cent, when complete combustion took place. The most violently explosive mixture of coal gas and air contains considerably more gas than 7.9 per cent. On the other hand, natural gas and methane behaved differently; there was a sharp dividing line (at the lower limit) between a mixture that would not explode and one that would. Thus with 4.9 per cent of gas no ignition took place, whereas with 5 per cent of gas there was a pronounced explosion.

EFFECT OF CARBON DIOXIDE ON EXPLOSION LIMITS.

As a result of recent experiments, J. K. Clement, physicist of this bureau, finds that the presence of carbon dioxide in mixtures of methane and air, or of the natural gas used at Pittsburgh and air, reduces the explosibility of the mixture to a much greater extent than the presence of nitrogen, and attributes this effect to the high specific heat of carbon dioxide. Under the conditions of his experiments the mixture of natural gas and air, with no carbon dioxide, was found

to have explosive limits lying between 5.5 per cent, low limit, and 11.6 per cent, high limit. He found that natural gas when mixed with air containing 2.5 per cent of carbon dioxide had explosive limits lying between 5.7 per cent, low limit, and 10.5 per cent, high limit. The mixture of air and carbon dioxide with which the natural gas was mixed had the following composition:

	Per cent.
CO_2	2.5
O_2	20.6
N_2	76.9
	100.0

When the gas was mixed with air in which 5 per cent of the air had been replaced by carbon dioxide the explosive limits were between 6.2 per cent, low limit, and 9.7 per cent, high limit. In this case the mixture of air and carbon dioxide with which the natural gas was mixed had the following composition:

	Per cent.
CO_2	5
O_2	20
N_2	75
	100

When natural gas was mixed with air in which 95 per cent of the nitrogen had been replaced by carbon dioxide, an explosion could be obtained only when 8.4 per cent of natural gas was present. When the gas was mixed with air in which 31 per cent of the nitrogen had been replaced by carbon dioxide, the explosive limits lay between 6 and 11 per cent. When natural gas was mixed with air in which 4 per cent of the oxygen of the latter had been replaced by carbon dioxide, the explosive limits lay between 5.2 and 10.5 per cent. When mixed with air in which 6.3 per cent of the oxygen was replaced by carbon dioxide, no explosion occurred. Nearly similar results were obtained when methane was used in place of the natural gas.

It will be seen that carbon dioxide exerts an influence upon an explosive mixture of natural gas or methane and air even when the proportion of oxygen is not greatly reduced. At the Frameries testing gallery in Belgium the precaution is taken of removing the carbon dioxide from the pit gas that is used at that place.

TEMPERATURE OF IGNITION.

Dixon and Howard[a] obtained the following ignition temperatures when the gases under investigation were mixed with air:

	°C.
Hydrogen (about)	585
Moist carbon monoxide	651
Methane	650–750
Ethane	520–630

a Chemical News, vol. 99, 1909, p. 139.

They state that neither changing the proportions of the gas mixture nor varying the rate of flow (both between wide limits) had an appreciable effect upon the values they obtained.

Freyer and Meyer[a] obtained the following values when they allowed the gas-air mixtures to flow freely through a tube:

	°C.
Methane	650-750
Ethane	606-650

While the following results were obtained when the mixtures were in a closed space:

	°C.
Methane	606-650
Ethane	530-606

In view of these results, the presence of ethane in the natural gas used at Pittsburgh gives the gas a slightly lower ignition temperature than methane. The ignition temperature of coal gas is given as 600° to 655° C. by various writers. C. L. Cabot[b] makes the statement, on the basis of experiments conducted by himself, that the ignition temperature of the natural gas of western Pennsylvania is higher than that of coal gas.

AIR REQUIRED FOR COMPLETE COMBUSTION.

A computation based on the results of the analysis of natural gas given on page 66 shows that the largest proportion of gas that can be present in a mixture of natural gas and air, and yet undergo complete combustion, is 8.6 per cent, or, in other words, the proper ratio of gas to air to form the most explosive mixtures is 1:11.6. Mixtures of natural gas and air in this and other proportions were made, exploded over mercury in a Hempel explosion pipette, and the products of combustion examined with the following results:

Products of combustion of mixtures of natural gas and air.

	Volumes of—					
	Gas taken.	Gas and air.	CO$_2$ produced.	CO produced.	O$_2$ after combustion.	Gas found corresponding to CO$_2$ produced.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Sample No. 1	8.5	100.0	9.6		0.3	8.3
Sample No. 2	8.6	100.0	9.7		.4	8.4
Sample No. 3	8.6	100.0	9.7		.4	8.4
Sample No. 4	8.6	100.0	9.8		.1	8.5
Sample No. 5	8.7	100.0	9.7		.3	8.4
Sample No. 6	8.8	100.0	9.3		.3	8.1
Sample No. 7	8.8	100.0	9.7		.1	8.4
Sample No. 8	8.9	100.0	9.3		.3	8.1
Sample No. 9	9.3	100.0	8.7	0.7	.1	
Sample No. 10	9.5	100.0	8.7	1.0	.1	
Sample No. 11	11.0	100.0	6.2	5.8	.1	
Sample No. 12	11.0	100.0	6.0	6.0		

[a] Jour. Chem. Soc. (London), vol. 94, 1893, p. 257.   [b] Jour. Soc. Chem. Ind., vol. 11, 1892, p. 801.

These figures reveal several interesting facts. Theoretically those mixtures containing 8.6 per cent gas should undergo complete combustion with the consumption of all the oxygen present and with the production of an equivalent quantity of carbon dioxide. In samples 1, 2, 3, and 4 the quantity of carbon dioxide obtained did not exactly correspond to complete combustion of the gas, but it will be noted that a small percentage of oxygen was detected. The carbon dioxide equivalent of this oxygen plus the quantity of carbon dioxide produced gives a result equal to the quantity of gas taken, indicating that the analyses in total paraffins of the natural gas as cited are close to the truth.

In samples 5, 6, 7, and 8 not enough oxygen was present for complete combustion of the gas, that is, the proper ratio of gas to air (1 : 11.6) was exceeded. Even in samples 9, 10, 11, and 12, where a considerable percentage of carbon monoxide was produced, a measuarble quantity of oxygen could be detected.

The experiments are of further interest in showing the large quantity of carbon monoxide produced when an insufficient supply of oxygen was present. Undoubtedly carbon monoxide was formed in the combustion of samples 5, 6, 7, and 8, but in quantities too small for quantitative measurement by the means employed. Subsequently another mixture corresponding to sample 6 was prepared and exploded and carbon monoxide was detected by means of the blood reaction. In the analyses of samples 11 and 12, the gases left after combustion were passed through fuming sulphuric acid in order to see if any acetylene or other intermediate products of reaction were present, but none was detected.

Because of some difference of opinion regarding the products formed by the incomplete combustion of methane, experiments were performed in which mixtures of methane and air were exploded in a Hempel explosion pipette with not enough oxygen for the complete combustion of the methane, as follows:

EXPERIMENT NO. 1.

Original mixture: 9.90 volumes of CH_4 + 88.84 volumes of air =10.03 per cent CH_4.
Contraction due to explosion=17.39 volumes.
Volume of products found after combustion:

	Volumes.
CO_2	8. 27
CO	1. 73
H_2	1. 13
N_2	70. 22
O_2	None.
CH_4	None.
C_2H_4	None.
C_3H_2	None.
	81. 35

EXPERIMENT NO. 2.

Original mixture, 10.83 volumes of CH_4 + 89.00 volumes of air, = 10.96 per cent CH_4.
Contraction due to explosion = 15.20 volume.

Volume of products found after combustion:

	Volumes.
CO_2	6.80
CO	3.75
H_2	3.07
N_2	70.00
O_2	None.
CH_4	None.
C_2H_4	None.
C_2H_2	None.
	83.62

Inspection of the above results shows that no methane remained unburned; that all of the carbon of the methane oxidized either to carbon dioxide or to carbon monoxide, and that part of the hydrogen burned, leaving the remainder free in the residual gas.

Four references relative to the formation of carbon monoxide are used by R. T. Chamberlin.[a] They are substantially as follows:

1. The French fire-damp commission says that a mixture of methane and air containing 12 per cent of methane produces 3.9 per cent of carbon monoxide upon explosion.

2. Broockman states that the explosion of fire damp produces no carbon monoxide.

3. Heise and Herbst state that the elements carbon and hydrogen as combined in methane, never become separated except when sufficient oxygen is present for the complete oxidation of the two elements.

4. Beard, quoting Thomas, states that carbon monoxide forms as the result of the explosion of fire damp when the proportion of methane is increased above that in the most explosive mixture (9.57 per cent methane and 90.43 per cent air).

The results shown in the above table substantiate the conclusions of the French fire-damp commission and of Thomas, but contradict the findings of Heise and Herbst and of Broockman.

SENSITIVENESS OF GAS-AIR MIXTURES TO EXPLOSION.

An important factor in testing explosives for use in coal mines is the formation of that mixture of natural gas and air which is most sensitive to explosion.

H. Couriot says[b] that the most sensitive mixture of methane and air contains 9.5 per cent methane and 90.5 per cent air; in other words, the most sensitive mixture of methane and air is that in which the maximum quantity of methane undergoes complete combustion.

a Explosive mine gases and dusts, U. S. Geol. Survey Bull. No. 383, 1909, pp. 11, 12.
b Compt. rend., vol. 126, 1898, pp. 750-752.

F. Emich states[a] that the sensitiveness of the mixture may be determined by igniting the mixture when it is flowing slowly in a thin layer between two glass plates so arranged that the distance between them can be varied by measured amounts. Each plate has a platinum wire sealed in it, the terminal of the wire being flush with the inner side of the plate and exactly opposite the terminal in the other plate. He calls that mixture the most sensitive which requires the smallest spark for ignition. In other words, inflammability is inversely proportional to the length of the spark required for ignition. He found that inflammability is nearly proportional to pressure, and that a change in temperature had little effect on the point of ignition. In the case of a mixture of hydrogen and oxygen, an increase from ordinary atmospheric temperature to 380° C. increased the inflammability of the mixture by only one-fourth.

The most inflammable mixtures of hydrogen, methane, and carbon monoxide with oxygen that were obtained by Emich were as follows:

One volume of hydrogen and one volume of oxygen.
One volume of methane and three volumes of oxygen.
Two volumes of carbon monoxide and one volume of oxygen (moist).

A device similar to that used by Emich was tried at Pittsburgh for determining the most sensitive mixture of natural gas and air. The results showed that the most sensitive mixture contained between 8.5 and 9 per cent of gas. An 8.5 per cent mixture ignited as readily as a mixture containing 9 per cent of gas; in other words the mixture of gas and air that is most sensitive to ignition is about the same of that which is most violently explosive.

SUMMARY.

The results of this investigation may be summarized as follows:

1. The natural gas used at Pittsburgh varies so little in composition throughout the year that for the purpose to which the gas is put at the testing station the variation may be considered negligible.

2. The chemical and explosive reactions of a mixture of this natural gas and air are like those of fire damp; consequently, tests of explosives in the presence of such a mixture give a good indication of the probable result of using the explosives in the presence of fire damp.

3. A mixture of this natural gas and air appears to be better suited for use in testing explosives than mixtures of acetylene and air, and coal gas and air, or a mixture of methane with such gases as hydrogen or carbon monoxide.

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[a] Monatschr. für Chem., vol. 19, 1898, pp. 299–320; and vol. 21, 1900, pp. 1061–1078.

CHAPTER IV.

APPARATUS AND METHODS FOR PHYSICAL TESTS OF EXPLOSIVES.

By Clarence Hall.

PHYSICAL EXAMINATION.

At the Pittsburgh testing station a physical examination is made of all explosives submitted for official tests. This examination includes the determination of the average diameter, length, and weight of the cartridge, whether or not the cartridge has been redipped, the apparent specific gravity of the cartridge as determined by sand, and the color and consistency of the explosive.

The apparent specific gravity of the cartridge as determined by sand is an important item, because it enters directly into the formula for determining the maximum pressure of the explosive in own volume (in a space equivalent to that occupied by the explosive); it is also of importance in preparing charges for tests, because the effort is made to keep the specific gravity of the explosive the same in all tests. The salient feature in the determination of apparent specific gravity by sand is the method employed to determine the volume of the cartridge. The same form of computation is necessary that is used in determining specific gravity by water, except that the weight of the sand displaced by the cartridge is divided by the density of the sand to determine the volume of the cartridge.

This method was devised to overcome two obstacles: (1) The impracticability of determining the volume of a cartridge by measurement because of irregularities in form, and (2) the impossibility of using water in determining volume because of the absorption of water by the explosive.

The color of the explosive is determined by comparison with the 48 typical colors printed in the Standard Dictionary under the word "spectrum."

In this bulletin the consistency of the explosives tested, if given, is reported according to two classifications. The older scheme gave the structure as granular, fibrous, or powdered. and the cohesiveness as very cohesive, moderately cohesive, slightly cohesive, and not cohesive. More recently, however, the classification of explosives with respect to their structure, etc., has been elaborated, and all explosives are now classified with regard to the following characteristics, as shown herewith:

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1. Granulation: Structure—(a) granular, (b) fibrous, (c) powdered; size—(a) very fine, (b) fine, (c) coarse, (d) very coarse.

2. Liquidness: (a) Very wet, (b) wet, (c) dry, (d) very dry.

3. Hardness: (a) Very hard, (b) hard, (c) soft, (d) very soft.

4. Cohesiveness: (a) Very cohesive, (b) moderately cohesive, (c) slightly cohesive, (d) not cohesive.

THE BALLISTIC PENDULUM.

The ballistic pendulum, illustrated in Plate I, B, is used to determine the relative weights of different explosives that, when fired, will produce equal deflections of the pendulum. Obviously, the ballistic test is purely comparative, and a standard explosive with which to make comparisons must be determined upon. The standard explosive selected for this purpose is a dynamite having the following composition: Nitroglycerin, 40 per cent; sodium nitrate, 44 per cent; wood pulp, 15 per cent; calcium carbonate, 1 per cent.

The quantity of this dynamite taken to make up the standard charge is one-half pound (227 grams). It is loaded in a prescribed manner, which is described later, and is fired with a No. 6 electric detonator.

The ballistic apparatus consists of two essential parts—the cannon in which the charge is fired, and the pendulum which receives the impact of the products of explosion and of the stemming.

The quantity of stemming used is always 1 pound, except for slow-burning explosives, for which 2 pounds are used.

The cannon is identical in form, dimensions, and construction with those used in gas and dust gallery No. 1 and with that used in making the flame tests. It is fastened by straps and rods to a four-wheeled truck, which runs on a 30-inch (76.2-centimeter) gage track. Behind the truck and 9 feet from the face of the mortar that constitutes the pendulum is a backstop or bumper. The cannon is carefully placed so that the axis of its bore is in line with that of the mortar.

The pendulum consists of a 12.2-inch (30.9-centimeter) United States Army mortar, weighing 31,600 pounds (14,333 kilos), which was supplied by the Bureau of Ordnance of the War Department. The mortar rests in a stirrup made of two machine-steel rods 1½ inches (3.8 centimeters) in diameter, each bent into a U shape. The ends of each of these rods are passed through two cast-steel saddles, which fit over a steel supporting beam. The supporting beam is 8 by 4 inches (20.3 by 10.2 centimeters) in section and 87 inches (221 centimeters) long. This beam is provided with two nickel-steel (3 per cent nickel) knife-edges, which are countersunk into its lower face near each end. (See fig. 1.) The knife-edges rest on bearing plates measuring 2 by 8 by 10 inches (5.08 by 20.3 by 25.4 centimeters)

and provided with small grooves to keep the knife edges covered with oil and protected from the weather. The bearing plates rest on base plates measuring 1 inch by 17 inches (2.54 by 43.2 centimeters) in section and 48 inches (121.9 centimeters) long, which are anchored by ⅝-inch (1.59-centimeter) bolts, 28 inches (71.1 centimeters) long, to the concrete piers between which the mortar swings.

The two concrete piers are each 51 by 120 inches (130 by 305 centimeters) at their bases, and 139 inches (353 centimeters) high. The inside walls of these piers are vertical, and the clearance between them is 60 inches (152 centimeters). The outside walls taper so that the piers are only 17 inches (43.2 centimeters) thick at the top. On one of the piers is a coupling box by means of which the electric circuit for firing the charges is completed.

The extent to which the mortar is deflected when the cannon is discharged into it is measured by an automatic recording device. This consists of a graduated scale with an index and vernier which are set on a steel base fastened to a concrete footing back of the mortar. The movable parts are actuated by a contact rod, set in guides, which
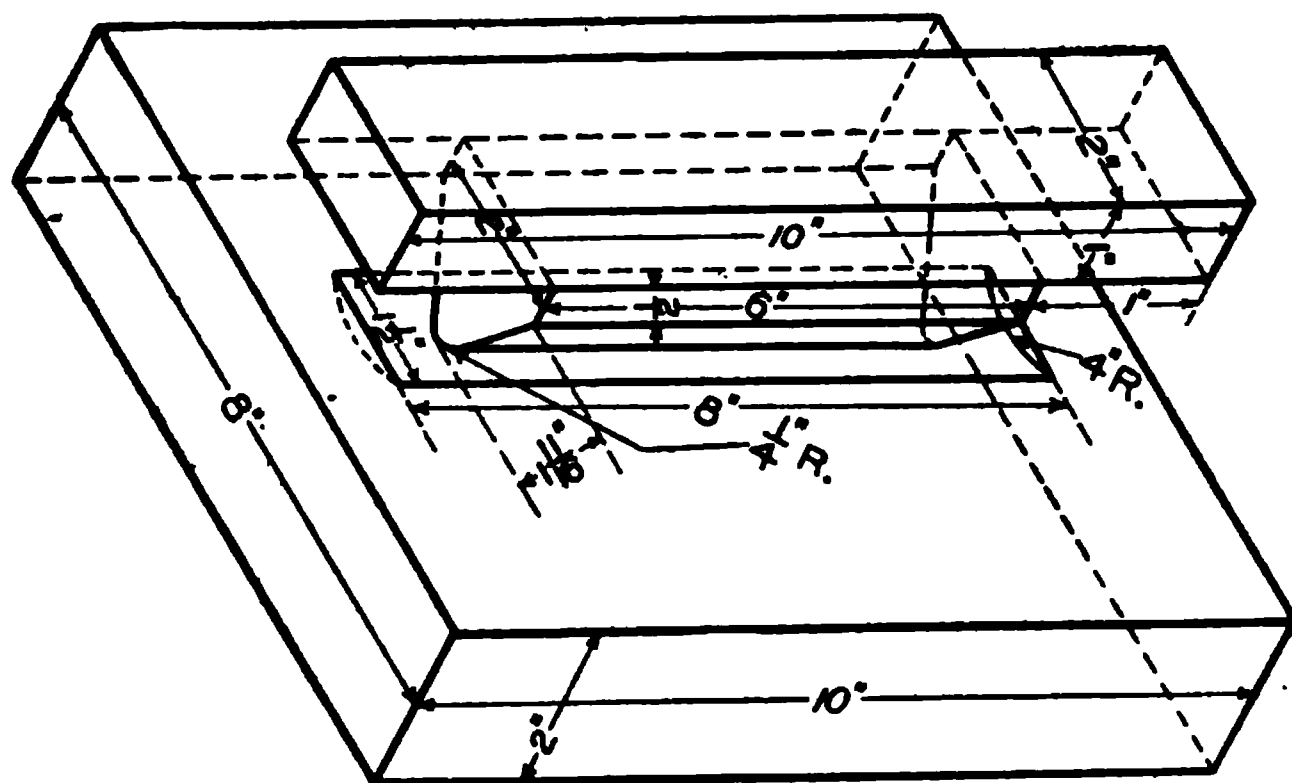
FIGURE 1.—Bearing plate and knife-edge of ballistic pendulum.

bears against a stud bolt in the bottom of the mortar directly below its center of gravity. The radius of swing of the mortar pendulum measured from the knife-edges to the base of the stud bolt is 114 7/16 inches (291 centimeters). The radius of swing measured from the knife-edges to the center of the trunnions of the mortar is 89¾ inches (228 centimeters). The scale, with its index and vernier, is detachable, and when not in use is carefully stored to protect it against the weather. The recording device measures the swing of the pendulum to within 0.01 inch (0.254 millimeter).

METHOD OF CONDUCTING TEST.

The cannon is loaded with a carefully-weighed charge in which an electric detonator of the strength required by the character of the explosive has been inserted. After the charge is tamped, the

A. GAS AND DUST GALLERY NO. 1.

B. BALLISTIC PENDULUM.

cannon is rolled up within $\frac{1}{16}$ inch (1.59 millimeters) of the muzzle of the mortar. This distance is fixed by stops on the track which meet the front wheels of the truck carrying the cannon. The legs of the electric detonator or igniter are then connected to the electric firing line, and when all is secure the man in charge of the loading inserts a safety plug (which he has until then carried, and without which the charge can not be exploded) in its proper place in the coupling box, retires a safe distance to where the firing machine is located, and explodes the charge.

The loading and tamping are done with tamping sticks of uniform pattern, and care is taken to use as uniform pressure as possible. The stemming is dry clay. As already stated, 1 pound (0.45 kilo.) is used for detonating explosives and 2 pounds (0.91 kilo.) for explosives like gunpowder that require a greater degree of confinement in order that they may produce their maximum effect. The method of charging and tamping used here is followed in charging and tamping the explosives used in the other tests made at the Pittsburgh testing station, when stemming is used.

The deflection produced by exploding equal weights of the standard dynamite varies slightly, even though the charges are tamped in the cannon with the same pressure, stemmed with the same weight of fire clay, and fired by the same grade of detonator. Several factors produce this variation. One is the position of the knife edges supporting the pendulum mortar, and to eliminate as nearly as possible the variation from this source the knife edges are trammeled before each trial. Other factors effecting the deflection are the direction and velocity of the wind, the condition of the bore hole in the cannon, and variations in the condition of the charge due to slight and unavoidable differences in the pressure used in loading and tamping. No one of these factors can be absolutely eliminated, but to reduce their effect to a minimum the explosive under examination is tested directly against the standard dynamite, both being handled and charged by the same person and the tests conducted on the same day and as nearly as possible under the same conditions. This procedure tends to eliminate the personal equation, through its effects becoming nearly uniform, and to minimize the variation produced by the wind, since the latter is fairly uniform during the period of test. The effect produced by variation in the condition of the bore hole is the most difficult factor to eliminate.

In detail, the procedure adopted in making a test is as follows:

Three trials of one-half pound (227 grams) charges of the standard dynamite are made and the average swing noted. Tentative trials of the explosive under test are then made until the charge gives a swing approximately that of the average swing produced by the

standard dynamite. This result is then confirmed by three trial rounds of the explosive under test. If the average swing from these three rounds is within 0.2 inch (0.5 centimeter) of the average swing produced by the standard dynamite and if the three swings do not vary more than 5 per cent, the test is accepted as satisfactory.

The "unit deflective charge" of the explosive under test, or, in other words, the weight of the explosive which will produce a swing exactly equal to that effected by the standard charge is then found by the following equation:

The average swing produced by the explosive under test : the average swing effected by the standard dynamite = the actual weight of the explosive under test : the unit deflective charge.

The unit deflective charge thus determined is the unit charge used in tests 1, 2, and 3 in gas and dust gallery No. 1.

GAS AND DUST GALLERY NO. 1.

Gas and dust gallery No. 1 (Pls. IA, and II) is designed for the purpose of ascertaining the effects of explosives when fired under known conditions into explosive mixtures of mine gas and air, of coal dust and air, or of mine gas, coal dust, and air. A further purpose is the ascertaining of the extent to which water vapor, incombustible dusts, or other substances may diminish the inflammability of such mixtures, or may delay or prevent the propagation of explosions within them. Other logical uses of such a gallery will be apparent.

The gallery simulates a gallery or room within a coal mine, and the gun chamber in which the explosives are fired simulates a bore hole in the coal or rock of such a mine.

The gallery is a cylinder 100 feet (30.48 meters) in length, with a minimum diameter of 6½ feet (1.93 meters), and is closed at one end by a concrete head. It is built of boiler-plate steel in five divisions, each consisting of three smiliar sections. Each section is 6⅔ feet (2.03 meters) long, and is built up of in-and-out courses.

The different sections of the gallery are, for convenience, numbered consecutively from 1 to 15, beginning with the section nearest the concrete head. Sections 1, 2, and 3 are made of ½-inch (1.27-centimeter) steel plates; sections 4 to 15 inclusive are made of ⅜-inch (0.95-centimeter) steel plates. The tensile strength of the steel used is not less than 55,000 pounds per square inch (3,867 kilograms per square centimeter). The tubes forming each section are held together by lap joints. On the interior of the gallery there is at each lap joint a 2½-inch (6.4-centimeter) circular angle iron, forming a ring around the gallery. By means of semicircular washers, studs and wedges, a paper diaphragm may be so secured to these angle

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irons as to partition off any portion of the gallery that may be desired, thus forming a closed space, of any desired volume within the capacity of the gallery, in which to inclose the mixture of gas and air, of coal dust and air, or of gas, coal dust, and air.

Each section of the gallery is provided with a release-pressure door (fig. 2), which is placed centrally on top of the section. These doors not only provide a vent by which the gases may immediately escape after an explosion and act as safety valves to prevent the destruction of the gallery, but they also afford an approximate means of estimating the pressure developed within the gallery. Each door when closed rests upon a rubber gasket, and is provided on its back

FIGURE 2.—Details of release-pressure door, window, section of joint of shell, etc., of gas and dust gallery No. 1.

with a rubber bumper to prevent its destruction when thrown open violently. In using the gallery each door may be left open, may be closed and left unfastened, or may be closed and fastened by means of stud bolts, as seems most suitable under the conditions of the experiment being made.

Each section of the gallery is provided with a plate-glass window $\frac{3}{4}$ inch (19 millimeters) in thickness and $5\frac{7}{8}$ inches (14.9 centimeters) square. By means of these windows the progress of any flame produced in the gallery may be easily noted. An indicator cock, tapped into the central section of each division, provides an opening through

which samples of the gas-air mixture, with which the gallery is charged, may be drawn for analysis.

The gallery rests on a reenforced concrete foundation which is 10 feet (3.05 meters) wide and 2 feet (0.61 meter) thick at the center, but it is carried up 4½ feet (1.37 meters) on the sides of the gallery where it is finished off with a coping. A narrow gutter cut in the concrete extends under the gallery for its entire length and, in connection with 1-inch (2.54-centimeter) holes opening into it from each section of the gallery, insures an effective means of drainage. These holes are closed by plugs when the gallery is in use.

Sections 1, 2, and 3 are covered with an insulating jacket to assist in maintaining at constant temperature any gas-air mixture within the gallery. This jacket is made up of magnesia-asbestos blocks, asbestos cement, a layer of 6-ounce duck, and strips of waterproof roofing paper. The jacket as a whole is treated with a thick coat of graphite paint.

The explosives are fired in a cannon which is embedded in the concrete head of the gallery in such a manner that the axis of its bore coincides with the longitudinal axis of the gallery. The cannons used are cylinders 24 inches (61 centimeters) in diameter by 36 inches (91.4 centimeters) long, and they each have a bore hole 2¼ inches (5.72 centimeters) in diameter and 21½ inches (54.6 centimeters) deep. In constructing them, various methods and materials have been used in an endeavor to make a cannon which would best resist the shattering and erosive effects of the explosions. The simplest cannon was made in one piece by boring out a low-carbon or nickel-steel forging to form a chamber or bore hole of the desired size. In another form of construction, illustrated in figure 3, the cannon consists of a cast-steel jacket surrounding a chambered liner of forged nickel-steel. The nickel steel used in these liners contains from 1.5 to 3.5 per cent of nickel.

In a built-up cannon the jacket is a hollow cylinder, 36 inches (91.4 centimeters) long, 24 inches (61 centimeters) in external diameter, 9½ inches (24.1 centimeters) in internal diameter for a distance of 28¼ inches (71.8 centimeters) from one end, and 7½ inches (19 centimeters) in internal diameter for the remainder of its length. The liner is made to fit the hole in the jacket, but it is 36¾ inches (93.3 centimeters) long, and when the parts are assembled its smaller end extends three-fourths of an inch (1.9 centimeters) beyond the jacket.

In assembling these built-up cannons, the jackets are shrunk onto the liners.

The concrete head, which completely closes one end of the gallery, is 11 feet (3.35 meters) high, 12 feet (3.66 meters) wide, and 8 feet (2.44 meters) long. The iron shell of the gallery is embedded 3 inches (7.6 centimeters) in the concrete head and is tied to it by

means of eight barbed anchor bolts each 8 feet (2.44 meters) long and ⅝ inch (15.9 millimeters) in diameter, running from angle irons riveted to the shell.

The concrete head is reinforced by many pieces of scrap iron, but especially by four 6-inch (15.2 centimeter) I beams each 10⅓ feet (3.15 meters) long, placed two on each side of the head and flush with the sides. These I beams are joined in pairs by ⅜-inch (9.5-millimeter) rods; each pair by two rods.

The cannon has its muzzle flush with that face of the concrete head which closes the end of the gallery. Directly back of the cannon there are seven cylindrical rubber bumpers, each 6 inches (15.2 centimeters) in diameter and 3 inches (7.6 centimeters) thick. These rubber bumpers are fastened to and held in place by 24 by 24 by 12 inch (61 by 61 by 30.5 centimeter) oak blocks, which are, of course, embedded in the concrete head.

Natural gas [a] is used in making the gas-air mixtures for the gallery. The gas is admitted into the first division of the gallery by means of a
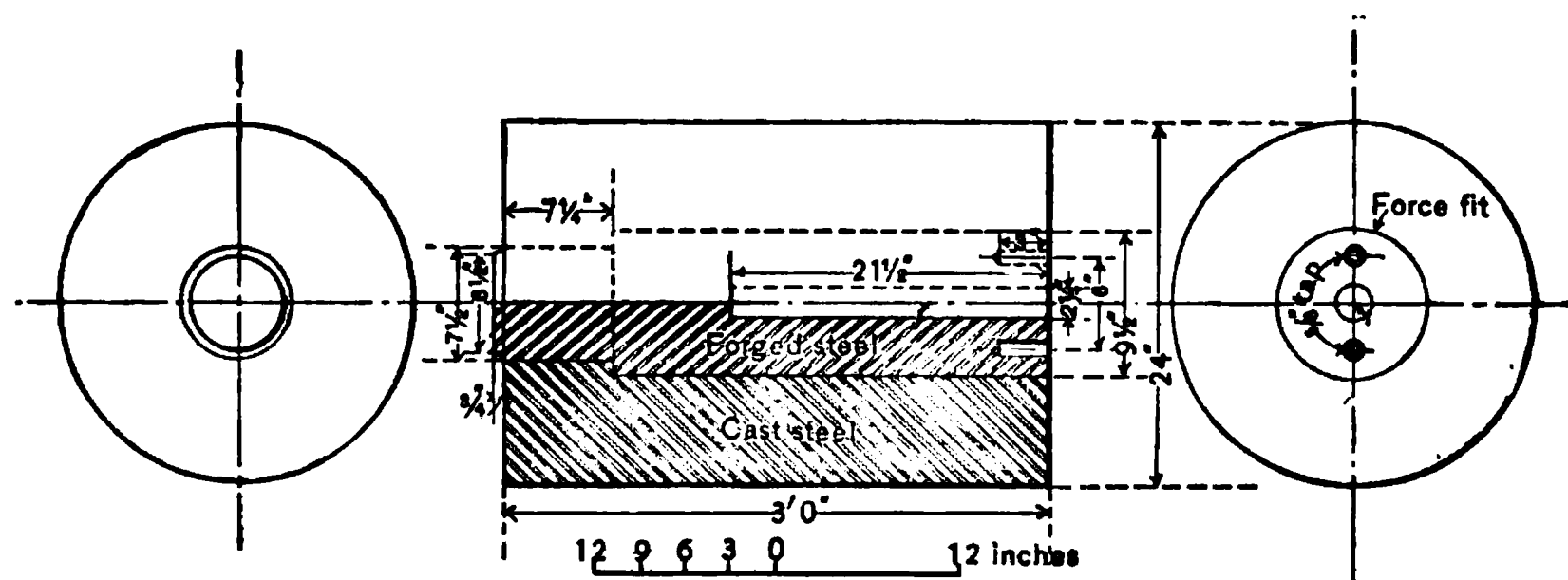
FIGURE 3.—Partial section and end views of built-up cannon.

2-inch (5.1-centimeter) pipe, 14 feet (4.27 meters) long, which is placed parallel to and within 2½ inches (6.4 centimeters) of the floor of the gallery. This pipe is provided with perforations of such dimensions and so placed that an equal flow of gas is maintained throughout each unit length of the pipe. The gas, as it enters the gallery, is measured by means of an accurate test meter which can be read to 0.05 cubic foot (0.0014 cubic meter).

The mixing of the air and gas is effected by circulating systems which are largely exterior to the gallery. The chief feature in each system is a No. 3 Sturtevant Monogram right-handed exhauster, with bottom horizontal discharge, operated by a direct-connected direct-current motor, having both bearings on one side of the exhauster and not exposed to the action of the gas. The exhauster case is rendered gas tight by a stuffing box through which the shaft passes. The case and flanges are of extra thickness. The circulat-

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[a] For analysis of the natural gas used at the Pittsburgh station, see p. 66.

ing system for the first division of the gallery is stationary and includes steam-heating coils by means of which the gas-air mixtures may be heated so as to maintain a constant temperature within the gallery. These steam-heating coils are so connected that they may be cut off from the circulating system at will by means of a by-pass into which the current of gas and air may be deflected by means of valves.

Each division of the gallery except the first is served by a common circulating system which is mounted on a truck so that it may be moved from point to point as desired. Each circulating system is provided with two 6-inch (15.2-centimeter) three-way iron stop cocks by means of which they may be cut off from the gallery to protect the exhauster from damage when an explosion takes place.

The interior of the gallery is provided with shelves made of ⅜-inch (9.5-millimeter) steel on which to place coal dust. Four of these shelves are placed, one above the other and 8 inches apart, on each side of the gallery, to which they are attached by means of brackets or studs. The shelves are each 20 feet (6.1 meters) long by 4 inches (10.2 centimeters) wide, and they extend in sections of the length given, throughout the gallery. In addition to these shelves a wooden bench or trestle is used for supporting coal dust in the first section of the gallery. The top of this bench is 20 feet (6.1 meters) long and 12 inches (30.5 centimeters) wide, and the height of the bench is such that its top is 9 inches (22.9 centimeters) below the axial line of the cannon and gallery. When used the bench is placed parallel to the sides of the gallery.

The coal dust used is ground to pass a 100-mesh screen by means of a cylindrical cast-iron Abbe pebble mill, whose interior is 26 inches (66.0 centimeters) in diameter and 24 inches (61.0 centimeters) in length. The mill turns on its horizontal axis at the rate of 60 revolutions per minute. It is provided with a 7 by 9½ inch (17.8 by 24.1 centimeter) opening in the side of the cylinder by which the mill may be charged or emptied. This opening is provided with two covers, one of which is solid and the other perforated with ½-inch (12.7-millimeter) holes, the latter being used to retain the pebbles while the coal dust is being emptied out of the mill. This dust is dumped into a hopper, which completely incloses the cylinder of the mill. From this hopper the dust is transferred to galvanized-iron cans in which it is stored until used. When coal is to be ground it is first broken by hand into small pieces, and 60 pounds (27.2 kilos) of these fragments are put into the pebble mill. The mill is started and the grinding is continued for three and one-half hours, when the product is sifted by means of a 100-mesh screen.

In order that quantitative tests may be made of the effect of moisture in preventing the ignition of coal dust or the preparation of explosions in mixtures of coal dust and air, the gallery is equipped

with a humidifying apparatus by which steam or water spray may be injected into the gallery so as to bring its atmosphere at a given temperature to the desired degree of humidity. For this purpose a Koerting exhauster, having a capacity of 240,000 cubic feet (6,797 cubic meters) of free air per hour, is connected by means of a wooden conduit to the 14-inch (35.56-centimeter) circular doorway in section No. 1. The similar doorway in section No. 15 is used as an air inlet, and it is connected by suitable wooden conduits to compartments containing the steam radiators and the humidifier. These radiators have 310 square feet (28.81 square meters) of heating surface. The wooden box in which they are inclosed is provided with one 10 by 12 inch (25.4 by 30.5 centimeter) hole and with 25 round holes 2 inches (5.1 centimeters) in diameter, through which air enters the box, and a wooden baffle-board, which directs the course of the air about the radiators. The heated air then passes upward to the long, narrow compartment containing the humidifying heads, from which water is sprayed by means of compressed air and when thus moistened the air passes through the opening in section No. 15 into the gallery. Obviously, to operate the humidifying apparatus the mouth of the gallery must be closed. For this purpose, brattice cloth and paper diaphragms are used.

Ten humidifying heads are placed in the compartment, five being arranged on either side, and they are so installed that any or all may be used as desired. They are fed from a water tank, the bottom of whose overflow orifice is 1½ inches (3.8 centimeters) below the discharge point of the head. Compressed air at a pressure of from 55 to 65 pounds per square inch (3.87 to 4.57 kilograms per square centimeter) enters the box by means of a ½-inch (1.27-centimeter) pipe. Under these conditions each humidifying head will deliver 30 pounds (13.6 kilograms) of water per hour.

As the blast from the gallery when the explosive mixtures are fired is very destructive, two concrete barricades 8 feet (2.44 meters) high, 30 feet (9.14 meters) long, and 3½ and 13 feet (1.07 and 3.96 meters) wide, respectively, at the base are erected on each side of the mouth of the gallery, and a swinging plate 6 feet (1.83 meters) wide, 9 feet (2.74 meters) long, and ½ inch (1.27 centimeters) thick is suspended on a framework directly across and at a distance of 50 feet (15.24 meters) from the mouth of the gallery, so as to arrest any flying stemming or other material that may be blown out of the gallery.

In order to provide a safe position from which the cannon in the gallery may be discharged and from which the phenomena that occur may be watched, an observation room 40 feet (12.20 meters) long and 9 feet 5 inches (2.87 meters) wide is arranged about 50 feet (15.24 meters) distant from and on the left-hand side of the gallery, facing the breech of the cannon. The walls of this room are of brick, 18

inches (45.7 centimeters) in thickness. The line of vision passes through a plate-glass window 37 feet (11.28 meters) long, 6 inches (15.2 centimeters) wide, and ½ inch (1.27 centimeters) thick. This window is protected externally by two projecting wooden guards, each one being 37 feet (11.28 meters) in length and 3 feet (0.91 meter) wide. In this observation room the meter, with which the natural gas is measured, and the electrical firing device, with which the cannon is fired, are installed and the coal dust is stored. A table is also provided for the engineers engaged in conducting the tests.

METHOD OF CONDUCTING TESTS.

All explosives were subjected to five tests, as follows:[a]

Test 1.—Ten shots, each with a charge equal in deflective force to one-half pound (227 grams) of 40 per cent nitroglycerin dynamite as determined by the ballistic pendulum, are fired in their original wrappers, with 1 pound of dry fire-clay stemming, at a gallery temperature of 77° F., into a mixture of gas and air containing 8 per cent of methane and ethane. An explosive is considered to have passed this test if all 10 shots fail to ignite the mixture.

Test 2.—Ten shots, each with a charge equal in deflective force to one-half pound (227 grams) of 40 per cent nitroglycerin dynamite as determined by the ballistic pendulum, are fired in their original wrappers, with 1 pound of dry fire-clay stemming, at a gallery temperature of 77° F., into a mixture of gas and air containing 4 per cent of methane and ethane and 20 pounds of bituminous coal dust, 100-mesh fine, from the Pittsburg bed, 18 pounds of which are placed on shelves laterally arranged along the first 20 feet of the gallery, and 2 pounds placed near the inlet of the mixing system in such a manner that all or part of the dust will be suspended in the first division of the gallery. An explosive is considered to have passed this test if all 10 shots fail to ignite the mixture.

Test 3.—Ten shots, each with a charge equal in deflective force to one-half pound (227 grams) of 40 per cent nitroglycerin dynanite as determined by the ballistic pendulum, are fired in their original wrappers, with 1 pound of dry fire-clay stemming, at a gallery temperature of 77° F., into 40 pounds of bituminous coal dust, 100-mesh fine, from the Pittsburg bed, 20 pounds of which is to be distributed uniformly on a horse placed in front of the cannon and 20 pounds placed on side shelves in sections 4, 5, and 6. An explosive is considered to have passed this test if all 10 shots fail to ignite the mixture.

Test 4.—A limit charge is determined within 25 grams by firing charges in their original wrappers, unstemmed, at a gallery temper-

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ature of 77° F., into a mixture of gas and air containing 4 per cent of methane and ethane and 20 pounds of bituminous coal dust, 100-mesh fine, from the Pittsburg bed, arranged in the same manner as in test 2. The limit charge is repeated five times under the same conditions before being established.

Test 5.—Same as test 4, except that 2 per cent of methane and ethane is used instead of 4 per cent, and that one shot is fired instead of five.

In tests 1, 2, and 3, 2 pounds of dry fire-clay stemming is used with slow-burning explosives.

Five different methods have been used for charging the cannon, depending in each case upon the class of explosive to be tested and the test to which it is to be subjected. The classification of the explosives employed for this purpose and the methods used are as follows:

Method A.—The method used for all explosives containing nitroglycerin, in which the object of the test is the determination of the limit charge, is as follows: In charging, a primer 2 inches (5.1 centimeters) long is cut from one of the cartridges and retained. The remaining cartridge or cartridges are cut on both sides and across each end and tamped firmly into the bore hole. No additional pressure is exerted after the charge completely fills the bore hole. An electric detonator of the kind and grade recommended by the manufacturer is then inserted in the center of the primer, and the whole is gently pressed against the charge. The condition of the charge is then investigated by the engineer, and care is taken to see that no small particles of the explosive are left in the bore hole in front of the charge.

Method B.—For all ammonium nitrate explosives which contain no nitroglycerin and with which the object of the test is the determination of the limit charge, the method of charging is the same as that given in method A, except that the cartridges are rolled until soft before being charged, and the tamping is done gently instead of firmly.

Method C.—In the case of all black blasting powders and similar explosives, whether or not the test is for the determination of the limit charge and whether or not stemming is used, the entire charge is tamped firmly, and then the electric igniter is inserted directly in the charge. If stemming is used, 2 pounds of it are put in, 1 pound at a time, and pressed home firmly. The last pound is tamped very hard.

Method D.—In the case of all explosives containing nitroglycerin, but with which stemming is used in the test, the 2-inch (5.1-centimeter) primer is first inserted in the bore hole and the split cartridges tamped firmly in front of and around it. This method presents a plane surface of the explosive to the stemming.

Method E.—All ammonium-nitrate explosives which contain no nitroglycerin, but with which stemming is used in the test, belong to class E. The method of charging them is the same as for class D, except that the cartridges are rolled until soft before charging them, and the stemming is put in gently instead of firmly.

For stemming, plastic milled fire clay, dried to 0.42 per cent of moisture and ground to 20-mesh fineness, is used. The fire clay is used dry because when used wet the maintenance of that uniform percentage of moisture in the clay necessary in comparative test work is impracticable.

The allowable limit of variation in the temperature of the gallery is 10° F. above or below the stated percentage, the aim being to eliminate extreme conditions of temperature. As all tests reported in this bulletin were made during the winter and spring, it was necessary to heat the gas-air mixture used. In tests made during the summer it is necessary to cool the gas-air mixture. Cooling is accomplished by spraying the outside of the gallery with water.

In all tests in which natural gas is used the allowable limits of variation of methane plus ethane in the gas-air mixture is one-quarter of 1 per cent above or below the stated percentage unless the analysis indicates a more sensitive mixture and there is no ignition.

To insure uniformity in mixing the gas and air the following time intervals obtain:

Heating the air in the gallery: This is continued until the temperature in the gallery is well within the allowable range.

Running in the gas: Three minutes for test 1, two minutes for tests 2, 4, and 5.

Mixing the gas and the air: Six minutes for test 1, five minutes for tests 2, 4, and 5.

Starting sampling to turning off fan: One and one-half minutes.

Turning off fan to firing shot: One minute.

No attempt has been made to establish a limit charge above 1,000 grams because of the severe effects upon the cannon.

When natural gas is used is making the mixtures they are confined in the first division of the gallery by means of a large paper diaphragm.

In making tests 1, 2, 4, and 5, the doors are left open in sections 1, 2, and 3, the doorways being closed by means of small paper diaphragms which are held in place by heavy cast-iron washers. All doors are closed but unfastened in making test 3.

Contrary to expectations it has been found that a decrease in the depth of the bore of the cannon does not make any unstemmed test more severe, and that an increase in the diameter of the bore hole up to 3 inches, so long as the surface is not broken or irregular or does not slope abruptly, does not produce less severe conditions. As every shot in the cannon increases the volume of that part of the bore hole which the charge occupies, especially ·with large charges and with stronger explosives, it becomes a simple matter to always

maintain the diameter of the bore hole at 3 inches (7.6 centimeters) or less by filling the enlarged portion at the back with fire clay and asbestos rope until the remaining volume of the bore hole will no longer hold the charge.

A sample of the gas-air mixture is taken in every test in which natural gas is used. The apparatus for sampling consists of a bottle, a perforated rubber stopper, a rubber tubing, clamps, and a brass tube long enough to reach the center line of the gallery. The sample is taken over water, and the time required is from one to one and a quarter minutes. The gas chemist analyzes this sample and reports the percentage of natural gas therein. An analysis of the natural gas is made every week and the percentage of natural gas in the gas-air mixture is multiplied by the percentage of methane and ethane in the natural gas to get the percentage of methane and ethane in the gas-air mixture.

The result of every trial shot is recorded either as ignition or no ignition. At the trial a record is made of the number of doorways through which flame issued and the number of windows through which flame was seen. In test 3 record is kept of the number of doors that opened and closed, opened and stayed open, or remained closed; and, in all tests in which dust is used, note is made as to whether or not any charred dust has been formed. In the majority of tests no trouble is experienced in distinguishing an ignition from no ignition, as the flame is seen at least half the distance down the gallery, and charred dust is formed when an ignition takes place. However, in testing low explosives, when the limit charges are very small, say 100 grams or less, there is some difficulty in distinguishing ignition from no ignition, so here an arbitrary standard of an ignition has been fixed, which is as follows: When testing small quantities of low explosives, if it is difficult to distinguish an ignition from no ignition, determination should always be made that the flame was seen in at least one more doorway and one more window with the gas-air mixture than with a clean gallery, and, if dust was used in the test, that at least some small quantities of charred dust were formed, before the result of the trial was designated an ignition.

Except with the explosives Masurite M. L. F. and FFF black blasting powder, with which No. 7 electric detonators and electric igniters, respectively, were used, No. 6 electric detonators have been used with all explosives herein reported for the following tests: Ballistic pendulum, gas and dust gallery No. 1, flame, and explosion by influence.

A test was made to determine whether the No. 7 electric detonators would ignite a gas-air mixture containing 8 per cent of methane and ethane. Ignition of the mixture, either when the electric detonator was put in the bore of the cannon or was suspended freely in the mixture, was found impossible.

In order to utilize the gallery to the best advantage in regard to time, it occasionally became necessary when working three shifts of men to run some or all of tests 1, 2, and 3 before the "unit deflective charge" was obtained on the ballistic pendulum, in which event the charge used in these tests was always greater than the "unit deflective charge," as found by experiment.

RATE OF DETONATION APPARATUS.

Provided all other conditions remain the same, the shattering effect of an explosive varies with the velocity with which the explosion wave or explosive reaction travels through the charge of the explosive. In explosives fired by detonation this movement as measured in definite terms of time and length is styled the rate of detonation.

In every explosion, however initiated, the cross-sectional area that the exposed surface of the explosive immediately presents to the exciting cause, or agent, is a most important factor in determining the final effect. In all of the tests of detonating explosives that have been made at the Pittsburgh testing station, mercuric fulminate, or a mixture of this substance with potassium chlorate alone or with other substances, has been used in electric detonators as the exciting cause. To assure the exposure of a definite and uniform area of the explosive to the action of the electric detonator the explosive is placed in tubes of thin sheet iron 42 inches (107 centimeters) in length and 1½ or 2 inches (3.8 or 5.1 centimeters) in diameter. The variations in the diameters of the iron tubes used are permitted in order to meet the requirements of the different explosives to be tested and to allow for the different diameters of the cartridges in which they are furnished for use in blasting.

When the tube has been charged with the desired amount of the explosive to be tested, two copper wires are inserted through perforations in the tube and cartridge file, at a distance of 1 meter apart, so that the column of explosive between these wires is 1 meter long. The copper wires are each led to a recording chronograph. A No. 7 electric detonator is inserted in the tube, in one end of the column of explosive. The tube with its contents is then suspended in the firing chamber, the copper wires are connected up to the recording chronograph, and the electric detonator, which has been connected to a dynamo electric machine, is fired. Of the two copper wires passed through the tube, the one that is nearest the electric detonator is ruptured first. As the explosion wave proceeds through the column of explosive the second wire is eventually reached and ruptured. The time which elapses between the rupturing of the first and second wire measures the rate at which the detonation proceeds through the column of explosive.

The time which intervenes between the rupturing of the first wire by the explosion of the electric detonator and the rupturing of the second wire by the detonation of the last layer of explosive at 1 meter's distance from the first wire is measured by means of the Mettegang recorder shown in Plate IV, *A*.

The primary components of the Mettegang recorder are a soot-covered bronze drum so connected to an electric motor that it may be caused to revolve at any desired speed up to 105 revolutions per second; a 220-volt direct-current motor provided with a rheostat for controlling its speed; a vibration tachometer so connected to the bronze drum that the number of revolutions of the latter in unit of time are accurately measured for any speed between 50 and 105 revolutions per second; induction coils the primaries of which receive their current from an electric-lighting circuit having a terminal pressure of 220 volts; and platinum terminals placed about 0.25 millimeter (0.01 inch) from the surface of the rotating drum and in circuit with the secondaries of the induction coils, by means of which electric sparks are so projected against the surface of the drum as to disturb its sooty covering and produce tiny bright spots at the point of impact. These spots may be easily perceived by the aid of a microscope attached to the recorder.

The drum is 500 millimeters (19.69 inches) in circumference. The edge of this drum is provided with 500 teeth which may be made to engage an endless screw. A pointer attached to this screw passes over a dial reading to hundredths, thus indicating with great precision the distance intervening between the spots produced on the soot-covered surface of the drum. The drum is provided with six platinum terminals held by an insulated arm that may be so moved as to bring the points within any desired distance from the drum. Each one of these points may be put in series with one of the secondaries of the induction coils while the other end of the electric lead is grounded to the drum through the base which supports it. Only two of the platinum terminals are used in any single firing trial for the determination of the rate of detonation in a given explosive; the other four are held in reserve for future use.

In ascertaining by this method the rate at which detonation once nitiated is transmitted through a column or file of an explosive, the electric current used as the medium for transmitting the record is divided into two parts by passing it through two equal lamp resistances each of which, at the Pittsburgh testing station, consists of a series of from 5 to 20 16-candlepower lamps After independently traversing the cartridge file at the initial and final points, the two leads are jointly connected to one of the poles of the primary of the induction coil through which the current passes to the return conductor. The secondary of the induction coil is then connected

by one pole to the two platinum terminals and by the other pole to
the base supporting the drum as described. In the induction coil—
as is well known—any change of tension in the primary coil sets up
an induced current in the secondary coil, and this mutual induction
between the coils results in the production of a higher potential
difference at the terminals of the secondary coil, so that sparks of
considerable length and intensity may be obtained. In the earlier
part of the work at the Pittsburgh station circumstances were such
that coils provided with iron cores were used, and all the data for
rate of detonation test recorded in this bulletin were obtained with
iron-cored coils. By a readjustment of the apparatus, induction
coils without iron coils were made to give the desired kind of sparks,
and such coils have been used in all subsequent tests made at the
station.

The vibration tachometer, by which the speed of rotation of the
drum is measured, is connected to an auxiliary shaft that engages the
main shaft of the drum by gears, thus preventing any irregularity in
recording the speed due to slipping. This tachometer measures the
number of rotations of the drum, but, as the circumference of the drum
is accurately known, the distance per second which any point on the
periphery travels may easily be calculated. Hence, at the highest
speed of 105 revolutions per second, the distance of travel is 52.5
meters (172.2 feet) per second. At 50 revolutions it is 25 meters
(82 feet) per second. At 86 revolutions, the number commonly
used in the tests at the station, it is 43 meters (141 feet) per second.

The distance between the spots impressed on the surface of the
drum are, as has been previously intimated, accurately measured
by means of the filar eyepiece and the endless screw, the spots being
focused on the cross hairs of the eyepiece.

The iron tube containing the cartridge file is suspended in the
chamber whose exterior is shown in Plate III, and the explosive is
fired. This chamber is a circular pit that was formerly used as the
well of a gasometer. In adapting the pit to its new use the top of
the gasometer was cut off and placed at the bottom of the pit on a
bed of sawdust and the space between the gasometer and masonry
walls of the pit was filled with sawdust. The cover of the pit con-
sists of heavy timbers framed together and overlaid by 12 inches
(30.5 centimeters) of concrete reenforced by six I beams. Four
straps extend over the top and down to eight "dead men" planted
about 8 feet (2.44 meters) below the surface of the ground. The
pit is 16 feet (4.88 meters) in diameter and 11 feet (3.35 meters)
deep. A manhole in its cover provides an entrance to the interior.

METHOD OF CONDUCTING TEST.

The rate of detonation is measured through a cartridge file 42
inches (107 centimeters) in length. In making a test the separate

BUILDING 17, RATE OF DETONATION PIT, CYLINDER AND CONDUIT OF FLAME-TEST APPARATUS.

cartridges, having the paper cut from their ends to avoid the damping effect of its folds, are placed end to end in a sheet-iron tube 42 inches (107 centimeters) long and either 1½ or 2 inches (3.8 or 5.1 centimeters) in diameter, depending upon the diameter of the cartridges used. Two copper wires leading from the Mettegang recorder are passed 1 meter (3.28 feet) apart through the cartridge file and firmly secured. The charge thus arranged is suspended horizontally in the pit and exploded by an electric detonator placed in one end of the cartridge file. The drum of the Mettegang recorder is rotated at the desired speed, and the electric detonator is fired by an electric firing device placed near the recorder. As the wires that pass through the cartridge files are broken, spots are formed on the drum the distance between the spots at a constant speed of the drum being proportional to the time elapsing between the breaking of the wires. When the peripheral speed of the drum is 43 meters (141 feet) per second the smallest time interval which it is possible to measure is $\frac{1}{150000}$ part of a second, although with the distance between wires equal to 1 meter (3.28 feet) such refinement is not necessary.

All high explosives are tested in cartridges having a diameter of 1¼ inches (3.2 centimeters). If an explosive with this diameter fails to detonate completely, cartridges having a diameter of 1¾ inches (4.4 centimeters) are used. If an explosive should fail to detonate completely with 1¾-inch (4.4-centimeter) cartridges it is considered unsatisfactory and is not eligible for the permissible list.

If the explosive submitted for tests is not in cartridges of 1¼-inch (3.2-centimeter) diameter it is repacked, care being taken that the specific gravity as determined in the physical examination has not been altered.

The rate of detonation, which is expressed in meters per second, is computed from the speed of the drum and the distance between the spark points, as illustrated in the following example:

In the test of Carbonite No. 1 on March 20, 1909, the speed of the drum was 43,000 millimeters per second and the distance between spark spots 12.63 millimeters. Therefore, 43,000 millimeters were traversed in one second, 1 millimeter in $\frac{1}{43,000}$ seconds, and 12.63 millimeters in $\frac{12.63}{43,000}$ seconds. Hence, $\frac{12.63}{43,000}$ seconds is the detonation time for a 1-meter length of the explosive and one second is the detonation time for $\frac{43,000}{12.63}$ meters, or a 3,405-meter length of the explosive.

FLAME-TEST APPARATUS.

The flame-test apparatus is used to record, by photography, the relative lengths and durations of the flames produced by different explosives when they are detonated or fired under the following conditions. The test is based upon the belief that the greater the length of the flame that an explosive emits and the longer the time

during which that flame endures, the more frequent are the chances that such a flame, when shot into the atmosphere of a coal mine, will ignite inflammable or explosive mixtures of mine gas and air, of coal dust and air, or of mine gas, coal dust, and air. That the volume, density, conductivity, specific capacity, and temperature of the flame are, like the length and duration, important factors in determining its effect is recognized, but these must be ascertained and their effects measured by other means. Hence too great emphasis must not be placed on the value of the length and duration of the flame of explosives as an indication of their permissibility, for both the length and the duration of the flames of certain nonpermissible explosives are less than those of some of the permissible explosives, but the other variables, particularly the temperature of the flame, are of importance and must be taken into account. Furthermore, the particular manner in which the air offers resistance to the flame may so laminate and disperse the flame that, in conjunction with other causes, its height and duration may be materially reduced. This air resistance accounts for certain variations in tests of the same explosive.

It is evident that to compare the lengths and durations of different flames they must be measured from a common base line. This measurement may be accomplished by causing the explosion to take place at a certain fixed point and then, by means of a camera, observing the flame constantly at such a point that its apex is included in the field of view. This method is used at the Pittsburgh testing station, and the results that are pictorially set forth in this bulletin show the length and duration of the flames of different explosives. The length of each is indicated by its height in the photograph, and its duration by the length of the photograph.

The apparatus by which the results are obtained consists, essentially, of a cannon for detonating or firing the explosive, and a camera for photographing the flame. Many accessories are needed in order that the test may be successfully made. The most important are the devices employed to cut off all light rays from the camera except those emitted by the flame from the explosive.

The cannon used is identical in shape, dimensions, and size of bore hole with those used in gas and dust gallery No. 1. It is mounted vertically on a concrete foundation at a distance of about 18 feet (5.5 meters) from the lens of the camera. To cut off extraneous light rays it is incased in an iron cylinder, as shown in Plate III. This cylinder is made of ½-inch boiler plate in twenty-four sections. It is 20 feet (6.1 meters) high and 43 inches (109 centimeters) in diameter. It is provided with a door on one side just above the cannon, which affords an entrance into the interior, and through

which the charging of the cannon is effected.   When a test is to be made, the top of this cylinder is closed by covering it with black paper to cut off the sunlight.

The camera is installed in a dark room in building 17, and the cannon, with its stack, is mounted outside of the building.   The iron cylinder incasing the cannon is connected to the dark room by means of a 16-foot (4.9-meter) conduit made of sections of ¼-inch (6.35-millimeter) boiler iron, which is rectangular in cross section and made light-tight at all joints, especially where it is riveted to the cylindrical stack that rises about the cannon.   The conduit has a width of 12 inches (30.5 centimeters), but, although its bottom is horizontal and its sides vertical, its top inclines from a height of 8¼ feet (2.52 meters) above its bottom, at the point where it is joined to the vertical cylinder or stack inclosing the cannon, to 21 inches (53 centimeters) at the point where it ends inside of the wall of the dark room in building 17.   At this end, doors are placed in the conduit.

A vertical slit 8 feet (2.44 meters) long and 2 inches (5.1 centimeters) wide is cut in the vertical iron cylinder, or stack, inclosing the cannon, and this slit is so placed that its vertical center coincides with that of the conduit and with the lens of the camera by which it is viewed.   The top of the cannon constitutes the base line from which the lengths of the different flames are determined, and therefore the camera is so adjusted and fixed that the top of the cannon always occupies the same position on the field of view of the camera.   Hence the height of the flame above the top of the cannon measures the length of the flame produced by the explosive that has been detonated or fired in the cannon.

The duration of the flame is measured by continuously photographing the flame as it appears through the slit in the stack surrounding the cannon.   This continuous photograph is taken by making the record on a sensitized film wrapped about a drum that revolves at a determined and known rate of speed within the field of view of the slit in the stack.

The essential features, therefore, of the photographic device employed in this test are: A rotating drum to which the sensitized photographic film is affixed; a 220-volt motor, regulated by a rheostat, by means of which the drum is revolved; a quartz lens by which the rays of light from the flame are focused on the sensitized film; a semicircular shield, in which a stenopaic slit 76 by 1.7 millimeters (3 by 0.067 inches) has been cut, which is placed in front of the lens; a shutter which excludes the light from the photographic box at all times except when the photograph is being taken; and a light-tight box in which all of these parts except the motor are inclosed.

The drum has a circumference of 500 millimeters (19.685 inches) and a height of 100 millimeters (3.937 inches). A beveled gear on the bottom of the axle of this drum engaging with a gear on a shaft from the motor provides a means by which this drum is rotated at a known speed of 20 meters (65.6 feet) per second. The sensitized photographic films used in this test are 3⅞ inches (98.4 millimeters) wide and 20 inches (508 millimeters) long, and they are so placed on the drum that their ends overlap. These overlapped ends are held in place by gummed strips which are attached to each end of the film, and the films are further secured in the place assigned them by means of heavy rubber bands, which are placed about the top and bottom of the film as it is wound about the drum.

The speed at which the motor revolves is ascertained by means of a tachometer, which is calibrated to read directly in meters per second.

A quartz lens is employed, because it will not only focus the ordinary visible light rays, but also those invisible violet rays that are so largely present in the flames from explosives.

The shutter that eclipses the stenopaic slit and the quartz lens is operated by means of a rubber bulb; it is opened immediately before the shot is fired and closed immmediately afterward. A second shutter, at the opening of the conduit from the stack into the dark room, may be opened so as to illuminate the dark room by means of the light coming down the stack, except when the shot is fired. Although this shutter is then necessarily open in order that the flame may be exposed to the camera, the top of the stack is then closed by its paper envelope.

The semicircular shield with its stenopaic slit is placed directly in front of, close to, and concentric with, the drum on which the sensitized film is held, and excludes from the film all rays of light except those from the flame of the explosive.

The tachometer, connected directly to the motor shaft, gives readings not only for the revolutions per minute of the motor, but also readings in meters per second for the peripheral speed of the drum. A maximum peripheral speed of 20 meters (65.6 feet) per second may be obtained for the drum, and this is the speed of rotation that is used in tests of detonating explosives. With slow-burning explosives, however, the duration of the flame is so long that the flame apparently is carried around the complete circumference of the film so many times that the points where the flame begins and ends can not be determined. It is therefore necessary in testing such explosives to run the drum at a much slower speed; to provide for this the apparatus is equipped with an auxiliary shaft and four toothed gears, so that the peripheral speed of the drum is one sixty-fourth of the speed, as shown by the tachometer. For slow-burning explosives this slower speed is quite satisfactory.

A. METTEGANG RECORDER.

B   BICHEL PRESSURE GAGES AND ACCESSORIES.

METHOD OF CONDUCTING TEST.

The charge of explosive used is 100 grams. Shots are fired both with and without stemming. Of the explosives reported in this bulletin only one, namely, FFF black blasting powder, showed any flame when fired with stemming. When stemmed, the charge is loaded in its original wrapper so as to completely fill the bore hole of the cannon. The amount of stemming used is 1 pound, and the method of charging is the same as that for classes C, D, and E given for gallery tests. The electric detonator or electric igniter used, which is of the grade recommended by the manufacturer, is then placed in the center of the charge and the proper electric connections completed.

As high explosives give flames of very short duration, three or more photographs on a single film are taken of the flames from the same explosive, but in no case are photographs of different explosives taken on the same film. The films are developed and prints are made by the official photographer of the Pittsburgh testing station. As some time may elapse between the exposing and developing of the films they are stored in a light-tight tin can sealed with adhesive tape. Occasionally two photographs taken on the same film may so overlap that it is impossible to measure the duration of either one, in which event one or both of the tests must be made again. This accounts for the differences in dates which may be noticed on some records of tests of the same explosive.

When the cannon is charged the engineer retires to the dark room in which the photographic device is located, starts the drum, obtains the desired speed, opens the shutters, and fires the shot by means of an electric firing device. The film when developed shows a figure of certain dimensions. The length and duration of the flame of the explosive is determined from the vertical height and lateral displacement, as shown in the photograph.

In measuring the photograph it is to be recalled that the angle of the lens and its position between the film and bore of the cannon are such that the height of the photograph is to the height of the flame as 1 inch (25.4 millimeters) is to 32 inches (813 millimeters).

The length of the flame is measured in milliseconds or one-thousandths of a second. When the peripheral speed of the drum is 20 meters per second, a 1-millimeter width of the flame is equal to 0.05 milliseconds in time. As the length of the flame is measured to the nearest quarter millimeter, the smallest time interval measured is 0.0125 milliseconds.

On Plate V the upper figure shows photographs of three flames from the same permissible explosive, taken when the film was traveling at a speed of 20 meters (65.6 feet) per second; the lower figures

THE IMPACT MACHINE.

The impact machine (Pl. VI, *A*) is used to determine quantitatively the sensitiveness of explosives to explosion when they are struck by a known mass of steel moving at a known velocity while the explosive being tested rests on a steel surface. Naturally the machine admits of such changes that the sensitiveness to explosion through impact between moving and fixed masses of other metals than steel or other substances, either alike or unlike, may be determined, but only when the sample of explosive that is tested is subjected to a direct blow, such as the blow of a mass falling vertically and striking its anvil or buffer squarely. The machine does not admit of determining the sensitiveness of an explosive to explosion when struck tangentially, or, in the vernacular, "a glancing blow."

The machine consists essentially of a framework of steel rods which rise vertically from a massive iron base resting on a concrete pier. A steel rod 57 inches (1.45 meters) high and 2.25 inches (57.2 millimeters) in diameter constitutes the backbone or fundamental element of the structure. In front of this are two rods, between which the yoke and impact weight, or hammer, move. To the right of these, as one faces them, is a vertically driven threaded rod or precision screw, by which the adjustment of the known weight is effected and its height above the plunger stamp is determined.

Resting on the iron base is a case-hardened steel anvil, on which the charge of explosive to be tested is placed. This anvil is surrounded by a tubulated jacket, through which water of known temperature may be circulated. Thus the temperature of the anvil, and hence the temperature of the explosive resting on it, may be brought to a definite temperature.

Above the anvil and between the guide rods is a plunger stamp made of soft steel, which is held in place above the anvil on which it rests by a steel guide which forms a part of the base support for the vertical guide rods.

The steel hammer, whose fall determines the impact, is a cylinder of steel of known dimensions and weight. It is placed above the plunger and between the guide rods. Above it is a yoke that moves freely, up and down, upon the vertical guide rods. This yoke is provided with jaws so placed that the lugs on an endless chain, moving in a vertical cycle behind the yoke, may engage them, and thus the yoke, and any weight attached to it, may be raised to any desired height. By the aid of an electric magnet, the yoke may be magnetized or demagnetized at will. When magnetized it will attract and hold the steel hammer, and then the whole system may be raised, by means of the endless chain, to any desired height within the range of the machine; the yoke can then be demagnet-

ized at will, causing the release and fall of the steel hammer. The demagnetization may be accomplished automatically by means of a stop set at a predetermined height and provided with a device for arresting the flow of the electric current. The vertically driven precision screw mentioned above raises and lowers the demagnetizing stop, and this screw is geared to a recording device that measures the height from which the steel hammer falls, and hence the distance through which this hammer falls before it strikes the head of the soft-steel plunger, which in turn rests upon the anvil, or, in practice, upon the explosive that rests upon the anvil.

The weight of the hammer used in these tests is 2,000 grams (4.4 pounds). The weight of the soft-steel plunger stamp is 900 grams (1.98 pounds). The plunger stamp is floated with heavy lubricating oil in its guide to insure uniformity in resistance and in movement. The maximum height from which the hammer can be dropped is 100 centimeters (39.37 inches). As the effective impact on the explosive is inversely proportional to the area of the base of the stamp which rests upon the anvil, it is essential that the surfaces of the stamp and of the anvil which face each other shall be perfectly true and parallel, and this is accomplished by turning and grinding them in a precision lathe.

METHOD OF CONDUCTING TEST.

The charge of explosive used in an experiment is 0.02 grams (0.31 grains). This quantity is weighed on a balance, immediately wrapped up in tin foil, and placed in a desiccator (which contains no desiccating material), by which it is protected from the air and in which it is stored and transported until used. The pellet containing the explosive is in the form of a flat disk, having a diameter of 1 centimeter (0.394 inch).

In operating the machine the hammer is raised to a known elevation, the height chosen being selected by judgment. The stamp is lifted, the explosive is transferred from its tin-foil envelope and placed upon the anvil, and the stamp is gently pressed down upon it, so as to insure a good contact of the explosive with the surfaces of the anvil and stamp, and so as to hold the explosive in place. The explosive is allowed to remain in this position for a sufficient length of time to acquire, by heating or cooling, a temperature of 25° C. (77° F.), which is the temperature at which these tests are regularly made at the Pittsburgh testing station. The hammer is then allowed to fall. If no explosion occurs, the weight is raised to successively greater heights until an explosion is effected or the maximum range of the machine is reached. If explosion does occur, successive samples of the explosive are tested at successively lower initial heights of fall. Proceeding thus tentatively, a

A. IMPACT MACHINE.

B. CALORIMETER AND ACCESSORIES.

height of fall is reached such that no explosion follows impact, and yet if the hammer be raised only 1 centimeter above this height an explosion does follow impact. The lesser of these two heights is styled the maximum no-explosion height. This observation is confirmed by four additional trials. Should an explosion occur in these confirmatory trials, the test is repeated by choosing a maximum no-explosion height 1 centimeter less than before, and endeavoring to confirm this height by the four additional trials.

After every trial the anvil and stamp are thoroughly cleaned and a fresh sample is used for the next trial. As the anvil is hard and the stamp comparatively soft, all of the wear due to impact and explosion is on the stamp. A few drops of the hammer suffice to cause the face of the stamp to become flared and pitted. The stamp is therefore removed and trued up by turning and grinding.

THE BICHEL PRESSURE GAGE.

The Bichel pressure gage is employed to determine the maximum pressure that an explosive would exert if exploded or detonated in a space that it fills completely, all of the heat set free by the chemical reactions that take place being retained by the products of the explosion. This is a condition that never exists in practice, for a portion of this heat is always communicated to the walls of the inclosure in which the explosive is fired. As, however, the portion of the heat that is thus communicated is variable, it becomes necessary, in order to directly compare the different explosives tested with one another, to assume theoretical conditions and to provide means by which they may theoretically be attained. Even in the case where the material and cubical content of the chambers in which the explosives are fired is the same the pressures vary with the extent of the surface exposed in the chambers owing to the varying quantity of heat absorbed by the materials of which the chambers are composed. By varying to a known extent the areas of the confining surfaces, it is possible to measure the heat-absorbing effect of surfaces of known area, and, by combining this measurement with the recorded pressure, to estimate the total dynamic effect of the charge of the explosive tested. The result thus obtained is styled the maximum pressure of the explosive in its own volume, a phrase which assumes the existence of purely theoretical conditions.

This apparatus also affords a means for the collection and examination, by chemical and physical methods, of the gaseous, liquid, and solid products of the chemical reactions that take place when the different explosives are fired within it.

The essential features of the apparatus used are the cylinders in which the explosive is fired, the instruments by which the pressure developed in these cylinders is recorded, and the device by which

the heat distribution, or dissipation, is ascertained; but many accessories are needed to render the apparatus operative for the purpose intended.

The apparatus actually employed consists of two stout cylinders, one of which, styled No. 1, has an interior volume of 15 liters (915.345 cubic inches) and the other, styled No. 2, an interior volume of 20 liters (1,220.46 cubic inches). These cylinders are made of cast steel 12.5 centimeters (4.92 inches) in thickness. The heads of the cylinders are provided with gaskets made of lead, and are secured in place by 12 heavy stud bolts and an iron yoke, as shown in Plate IV, B. The smaller of the two cylinders has an exterior length of 31.5 inches (80 centimeters), an exterior diameter of 19.75 inches (50.2 centimeters), an interior length of 19 inches (48.3 centimeters), and an interior diameter of 7.875 inches (20 centimeters). The larger of the two cylinders has an exterior length of 31 inches (78.7 centimeters), an exterior diameter of 19.75 inches (50.2 centimeters), an interior length of 25.25 inches (64.1 centimeters), and an interior diameter of 7.875 inches (20 centimeters). A system of sheaves and suspended counterweights is provided to aid in detaching the heavy heads from the cylinders and mounting them upon the specially designed wagons so that access may readily be had to the interiors of the cylinders.

As the air is practically excluded from a bore hole in coal or rock when it is filled with a charge of explosive, these conditions must necessarily be simulated in experimental tests. Therefore the air is almost entirely removed from these cylinders when explosives are fired in them. This is done by pumping out the air until its pressure within the cylinder is reduced to 10 millimeters (0.3937 inch) of mercury.

To accomplish this reduction of pressure a well-glanded tube is inserted in a hole bored in an upper segment of each cylinder near one end, and this tube is connected with a rotary vacuum air pump driven by a 2-horsepower motor. With the device used, only a few moments are required to reduce the pressure in either cylinder to the desired extent. The connecting tube is provided with a valve which, when closed, excludes the outside air from the cylinder.

In the upper segment of the cylinder on the end opposite from the exhaust tube there is a second opening which accommodates the insulated plug that provides a means for conducting the electric current to the electric detonator and also prevents air entering the gage while it is being exhausted or gases escaping after the explosive has been fired and while a considerable pressure exists within the cylinder.

A third perforation is made in the top of each gage and a properly glanded tube inserted in this aperture is provided with a piston

0.3937 centimeter (0.1550 inch) in diameter which can be moved up and down within the tube and is resisted by a spring. Two different springs have been used at the Pittsburgh testing station. One of them exerts a pressure of 1 kilogram per square centimeter (14.22 pounds per square inch) for each 0.4 millimeter (0.015748 inch) of its pencil movement and the other for each 0.56 millimeter (0.022047 inch) of its pencil movement. Careful record of the spring used and its effect is noted in each experiment made.

A stylus is mounted on one end of a lever, the other end of which is fastened to the upper end of the stem of the piston in such manner that while free to move vertically it shall remain in the same vertical plane so long as the gases generated in the cylinder exert pressure upon the piston.

In testing this apparatus many different kinds of oil were used as lubricants about the piston, with the result that it was found that the inertia effects of the piston and the vibration effects in the spring were most completely eliminated when a heavy oil was used. Hence, in all the tests reported in this bulletin heavy cylinder oil at room temperature was used.

Attached to the upper part of each gage and to the rear of the piston rod bearing the stylus is a support carrying a drum on which is a paper ribbon. This drum is mounted so as to rotate horizontally about a vertical axis. The mechanism by which the drum is rotated is geared to an electric motor which runs at a constant speed, and by means of a speed counter the rate of rotation of the drum is accurately measured. Hence the curve drawn upon the indicator card, or paper ribbon, may be resolved with accuracy into its components of horizontal translation of the card and vertical elevation of the stylus at the different periods throughout the explosion. Usually the drum is rotated at a speed of 412 revolutions per minute.

Cylinder No. 2 is constructed in the same manner and fitted with similar appliances, but it is further provided with four solid cast-steel cylinders, which may be introduced into it at will so as to reduce the volume of the chamber while varying its cooling surface. The largest of these cylinders is 17.78 centimeters (7 inches) in diameter and 20 centimeters (7.875 inches) in height. The others are each 17.78 centimeters (7 inches) in diameter and 6.67 centimeters (2.625 inches) in height. Pressure gage No. 1 has a cooling surface of 3,914 square centimeters (607.8 square inches). When the large steel cylinder is inclosed in it pressure gage No. 2 has a cooling surface of 6,555 square centimeters (1016.0 square inches), and when the three small steel cylinders are inclosed in it the gage has a cooling surface of 7,624 square centimeters (1181.7

square inches). In calculating the results from the observed data, these cooling surfaces are respectively designated A, B, and C in the order enumerated above.

In the center of each gage there is a small wire support upon which the cartridge of explosive is laid, thus preventing the destructive effects on the walls of the gage which an explosive exerts when it detonates in contact with a surface.

METHOD OF CONDUCTING TEST.

The charge of explosive used is 100 or 200 grams (3.53 or 7.05 ounces), according to the character of the explosive as ascertained from a chemical analysis of the substance and from the previous tests in other apparatus. For this test the explosive is removed from its original wrapper and is wrapped in an envelope of tin foil in such a manner that its specific gravity is the same as when it was contained in its original wrapper.

The head of the cylinder is now removed. One leg of a No. 7 electric detonator is fastened to the wire that passes through the insulated plug on the upper segment of the cylinder and the other leg is grounded to the gage through the iron support with which it is in contact. The detonator is inserted and secured in the cartridge and the cartridge laid upon the wire support. The head of the cylinder is then replaced. The cylinder is now exhausted until the internal pressure equals 10 millimeters of mercury, and the motor which operates the drum is set in revolution. When everything is ready the charge is fired by an electric firing device and the indicator record is taken.

Three such tests are made in pressure gage No. 1, and the average result of these is accepted as the pressure existing when cooling surface A is present. Three similar tests are made with cooling surface B and with cooling surface C in pressure gage No. 2.

FIGURE 4.—Indicator and from Bichel pressure gage.

One of the indicator cards obtained is illustrated in figure 4, where the line M-N, through a portion of its length, indicates the fall of pressure in the gage caused by the cooling of the confined gases. Extending this line to the point marking the moment of explosion of the charge affords only a partial correction for error in the pressure reading due to the cooling of the gases.

However, on inspection of figure 5 it is noted that as the area of the cooling surface is increased the recorded pressure is decreased, and this suggests that the effects of the cooling surfaces may be eliminated and the maximum pressure in each case determined by platting the pressures against the cooling surfaces. An inspection of the average pressures obtained by this method shows that the points do not lie in a straight line. It therefore becomes necessary to devise

PRESSURE, KG. PER CM²

AREA OF COOLING SURFACE, CM²

FIGURE 5.—Graphic representation of formula for finding effect of cooling surfaces.

a formula by which to properly proportion the probable errors between these graphic results. The formula adopted and used at the Pittsburgh testing station in the preparation of the results set forth in this bulletin is derived as follows:

Let A=the pressure developed with cooling surface A.

B=the pressure developed with cooling surface B.

C=the pressure developed with cooling surface C.

x=the pressure with elimination of surface influence using A and B.

y=the pressure with elimination of surface influence using B and C.

z=the pressure with elimination of surface influence using A and C.

P=the pressure with elimination of surface influence and probable error.

$x_1 = x - B.$

$y_1 = y - C.$

$z_1 = z - C.$

Then by similar triangles (see fig. 5):

$$x_1 = \frac{6,555\ (A-B)}{2,641}$$

$$y_1 = \frac{7,624\ (B-C)}{1,069}$$

$$z_1 = \frac{7,624\ (A-C)}{3,710}$$

Then, averaging x, y, and z, giving each a value proportional to the difference in cooling surface between the points from which each is derived, and simplifying, gives $P = 1.911A + 0.5B - 1.411C$.

This pressure, P, divided by the charging density, which is defined as the volume of the charge divided by the volume of the gage, gives the maximum pressure of the explosive in its own volume after elimination of cooling-surface influence.

To simplify the computing of the pressure in its own volume, the formula $M = \frac{VPS}{W}$ is adopted, in which M represents the pressure exerted by an explosive, measured in kilograms per square centimeter, when the explosive is exploded in its own volume; V, the volume of the gage in cubic centimeters (this is always 15,000); S, the apparent specific gravity of the cartridge as determined in the physical examination; and W, the weight of the charge in grams.

METHOD OF COLLECTING PRODUCTS.

As has been stated, the Bichel pressure gage, by retaining the products of the explosive reaction, affords a means through which samples of the solid, liquid, and gaseous products may be taken for analysis and investigation, and through which the total quantity of matter in each of these states may be measured.

For this purpose a 200-gram charge of the explosive is fired in pressure gage No. 1. The method followed in preparing and firing the charge is the same as that employed in making the determination of the pressure, except that a Bourdon gage is substituted for the regular indicator mechanism, and that, before firing, the Bourdon gage is isolated from the chamber of the cylinder by closing the stopcock intervening between them. After the explosion the system is allowed to remain in this condition until the products of the combustion have cooled down to room temperature. When the gage no longer shows a decrease of pressure due to cooling of the gas the recorded pressure is noted. At the same time the barometer is read and with the data for temperature, gage pressure, barometric pressure, and volume (which is always 15 liters) the volume of the gases and vapors at $0°$ C. ($32°$ F.) and at a pressure of 760 millimeters (29.92 inches) of mercury is calculated.

The sample taken of the gases and vapors is drawn out through the valve to which the air pump was attached. It is allowed to escape from the gage slowly by cracking the valve, and a 200 cubic centimeter sample is collected over mercury in such a manner that a differential sample is taken during the entire time of the escape of the gases. In collecting the sample the mercury in the aspirator is allowed to run out, and the gases and vapors which follow it are drawn off until the pressure within the Bichel gage is reduced to that of the atmosphere. The sample of gases and vapors is necessarily a differential one, as it is drawn slowly and continuously while the pressure in the gage is constantly changing.

To collect and measure the liquid and solid products of the reaction, the head of the cylinder must be removed. The liquid products are then drawn off into a measuring vessel, and the solid products are scraped out and measured, preferably by weight. Of course, this is a rough way of reaching the result, since, among other difficulties, secondary reactions may take place as soon as the air strikes the products, and the material collected may not be identical with that immediately resulting from the reaction. However, no better method appears yet to have been devised. The methods employed for analyzing these products and for ascertaining the effects of the tin-foil wrapper and the components of the detonator on the character and proportions of the components of the reaction products will be described elsewhere.

THE CALORIMETER.

The calorimeter and accessories used at the Pittsburgh testing station are illustrated (p. 102) in Plate VI, B. The calorimeter is designed to measure the quantity of heat set free by the explosion or detonation of a known quantity of an explosive. It is constructed on the principles usually followed in calorimeters, by which the chemical reaction is carried on between the reacting bodies while they are immersed in a mass of water of known weight, the temperature of which is raised by receiving the heat set free by the reaction. The difference between the evolution of the heat in an explosion or detonation and that in simple combustion, as, for instance, in the combustion of coal, is one of time only, the rapidity of the reactions in explosion or detonation being greater than in simple combustion.

The apparatus employed consists of a steel bomb in which the explosion takes place; a vessel for holding a measured quantity of water in which this steel bomb is immersed; a wooden tub or cylinder which supports this immersion vessel and also insulates it; a stirring device by which the water in the immersion vessel is so stirred as to distribute the heat evolved throughout the mass of water about the bomb so as to produce a uniform thermal condition; a thermometer

registering a variation of 0.001° C.; a magnifying glass by which the divisions on the thermometer may be read; a pair of scales on which the parts of the system and the water used may be accurately weighed; and a frame by which the bomb loaded with its charge of explosive may be raised and deposited in place.

The calorimeter bomb is made of wrought steel 0.5 inch (12.7 millimeters) in thickness and is bottle-shaped. It is 30 inches (76 centimeters) in height and 9.5 inches (24 centimeters) in interior diameter in its cylindrical section. It weighs 158 pounds (72 kilograms), has a capacity of 30 liters (1,831 cubic inches), and is closed by a cap which makes an air-tight fit. Two ⅝-inch (15.9-millimeter) holes are tapped into this bomb on opposite sides of the neck, near the top. A ⅝-inch (15.9-millimeter) valve is screwed and sealed into one side of the neck and is connected by means of a ⅝-inch (15.9-millimeter) pipe and flexible rubber hose with a vacuum pump through which the pressure within the bomb may be reduced to 10 millimeters (0.4 inch) of mercury. On the side of the neck opposite that into which the exhaust valve is inserted is an opening through which the plug carrying the detonator and one of its legs is sealed, the other leg of the detonator being grounded to the bomb by means of an iron wire so looped that it can be firmly wedged within the nipple of the valve.

The immersion vessel is made of nickel-plated copper 1/16 inch (1.6 millimeters) thick. It is 30⅝ inches (78 centimeters) deep, 17⅝ inches (45 centimeters) interior diameter, and is strengthened by means of bands of copper wire wound upon the outside. The capacity of this immersion vessel is 7,750 cubic inches (127 liters).

The wooden tub or cylinder in which the immersion vessel is placed is made of wooden staves 1 inch (2.5 centimeters) in thickness and is strengthened by means of four brass hoops on the outside of the cylinder. The vessel has an internal diameter of 21 inches (53 centimeters) and a depth of 33 inches (84 centimeters).

The stirring device consists of a wooden frame supporting three steel rings, which are joined together by rods and stays. When this is adjusted to the calorimeter, the rings fit into the annular water-filled space between the bomb and the inner wall of the immersion vessel, while the exterior rods of the wooden frame run in guides fastened to the exterior of the wooden tub and serve as guide rods when the stirring device is raised and lowered by the electric motor and worm gear which actuates it.

When the parts of the calorimeter are assembled the steel bomb is supported on a steel frame resting on the bottom of the immersion vessel. Likewise the immersion vessel is insulated by means of a wooden support placed upon the bottom of the tub on which the immersion vessel rests. When the apparatus is in use the top of the

tub is covered with a snugly fitting board cover to reduce the loss of heat from the system through radiation.

As stated, the amount of heat given off by the chemical reactions going on in the calorimeter is measured by the rise in temperature of the water in which the bomb is immersed. If the water absorbed all the heat set free, the total number of heat units evolved could be easily determined from the weight and rise in temperature of the water. But manifestly the material of the bomb, the stirring device, the immersion vessel, and the thermometer will each absorb some of the heat, the quantity thus absorbed being dependent in general on the mass and specific heats of the material in each of these devices. It is necessary, therefore, to ascertain in advance the amount of heat that is taken up in this manner, and for convenience the result is stated in terms of the mass of water which is thermally equivalent to the mass of this other material. The result thus stated is styled the water equivalent of the calorimeter. The water equivalent found experimentally for this calorimeter is 11.55 kilograms (25.46 pounds). Furthermore, a certain amount of heat is evolved by the detonator when it is exploded, some of which is taken up by the tin-foil wrapping. Therefore, the heating effect of the detonator is also determined. The No. 7 detonators used at the Pittsburgh testing station develop 0.86 calorie.

Another effect to be noted in calorimetric work is the loss of heat by radiation into the atmosphere when the air is at a lower temperature than the system or the gain of heat from the atmosphere when the latter is at a higher temperature than the apparatus. To prevent any marked changes due to atmospheric influences, the calorimeter is installed in a small insulated room in building No. 17, and then, before firing, the temperature of the water is brought closely to that of the room. As the weights of explosive used and water taken are such that the final change in temperature of the water is less than 1.5° C. (2.7° F.), the error from this source is small, but it is corrected in the data tabulated under "rise in temperature."

METHOD OF CONDUCTING TEST.

The explosive is carefully removed from its cartridge so as to prevent any of its paraffin coating from becoming mixed with it and so as to retain its moisture content and the proportions of the ingredients of the mixture intact. A carefully weighed charge of 100 grams of the explosive, together with a No. 7 electric detonator, is then enveloped in 3.8 grams of tin foil so as to form a cartridge. This cartridge is suspended in the center of the bomb by passing one of the legs of the detonator through the side plug of the bomb and grounding the other leg to the bomb itself in the manner previously described.

The cap of the bomb is then screwed firmly into place so as to make an air-tight joint, and the air within is exhausted by means of the vacuum pump described under the Bichel pressure gages, until the pressure within the bomb is reduced to 10 millimeters (0.4 inch) of mercury. The bomb is placed in the immersion vessel, which, with the tub, thermometer, and stirrer, is resting on the scales, and the weight is noted. Water is then poured into the immersion vessel until the bomb is totally submerged, when the whole is weighed again, the increase in weight representing the added water. The cover is put on the tub and the stirrer is moved up and down until the temperature of the water becomes constant. Then the charge is fired electrically, and, with the stirrer still in operation, the rise of the mercury in the thermometer is noted up to the maximum.

In all computations the following formula is used:

$$C = 10[T(W+We) - 0.86]$$

in which C = large calories developed per kilogram of explosive.

T = rise in temperature in degrees centigrade after correcting for radiation.

W = weight of water in calorimeter in kilograms.

We = water equivalent of calorimeter in kilograms.

0.86 = heat evolved by a No. 7 electric detonator, in large calories.

10 = number of 100 grams in 1 kilogram.

The following data from a test are given in full to show what observations are made and the method of computing the result:

Date: April 9, 1909.

Explosive: Coalite No. 2D.

Observer: Hopkins.

Object: To determine the calorific value of the explosive.

Charge: One hundred grams in 3.8 grams tin foil.

Diameter, 3.2 centimeters; length, 10.2 centimeters; volume, 82.01 cubic centimeters.

Electric detonator: No. 7. Absolute pressure: 10 millimeters.

Temperature of room: 18° C.

	Kilograms.
Weight of calorimeter with water	251.58
Weight of calorimeter without water	168.12
Weight of water	83.46
Water equivalent of calorimeter	11.55
Total equivalent water	95.01

Thermometer used: No. 24.

Heat developed by a No. 7 electric detonator, 0.86 calories.

Calorimeter readings.

Time.	Temperature.	Difference.	Time.	Temperature.	Difference.
	°C.			°C.	
2.39 p. m.	19.583		3.07 p. m.	20.406	0.836
2.42 p. m.	19.576	0.007	3.12 p. m.	20.406	.000
2.45 p. m.	19.574	.002	3.17 p. m.	20.404	.002
2.48 p. m.	19.570	.004	3.22 p. m.	20.402	.002
2.51 p. m.a	19.570	.000	3.27 p. m.	20.400	.002

a Charge ignited.

$7.2 \times 0.002 = 0.014$ correction.

$20.400 + 0.0144 = 20.414$.

$20.414 - 19.570 = .844$ °C. rise in temperature.

$95.01 \times .844 = 80.19$ large calories per 100 grams of explosive and detonator.

$80.19 - .86 = 79.33$ large calories per 100 grams of explosive.

$79.33 \times 10 = 793.3$ large calories per kilogram of explosive.

SMALL LEAD BLOCKS.

The test with small lead blocks has for its object the determination of the compression effect which detonating explosives produce when they are detonated, unconfined, in close contact with a homogeneous substance which is uniformly compressed by impacts or pressures of equal magnitude. Cylinders of lead have been selected for these tests because the results obtained with them can in a measure be correlated with the results obtained by firing gunpowder and similar explosives in confined spaces, such as the chamber of a gun, for, since Rodman, in 1857, applied this method for measuring the pressures exerted by explosives, the compression test as modified by Woodbridge and Noble has been universally used as a measure of the efficiency of explosives in gun chambers.

There is, however, this difference between the conditions which obtain when explosives are fired in closed chambers with movable pistons, like a gun chamber closed by its projectile, and when explosives are detonated in the open, where the atmosphere acts as the movable piston, namely, that the mass of the piston in the latter case is relatively very small, and in order that its inertia may be made manifest, the chemical reaction that travels through the mass of the explosive must proceed at a relatively high velocity. This capacity of an explosive to produce compression or disruption when it explodes under atmospheric confinement only is designated as the percussive force of the explosive, and is manifest only in those explosives in which the explosion wave travels at so high a velocity that they may be styled high explosives.

METHOD OF CONDUCTING TEST.

The lead blocks are cylinders 1½ inches (3.8 centimeters) in diameter and 2½ inches (6.4 centimeters) in height. They are placed in testing upon a rigid support composed of a large piece of steel shafting, which is embedded in concrete. The standard charge of explosive used in the tests is 100 grams (3.5 ounces), and as this quantity of explosive when detonated would deform the lead cylinder beyond the possibility of accurate measurement, a disk of annealed steel 1½ inches (3.8 centimeters) in diameter and ¼ inch (0.64 centimeter) in thickness is placed upon the cylinder in order to receive the immediate effect of the impact. The lead cylinder, therefore, records only the transmitted effect of the explosion.

In preparing the lead cylinder for the test after the steel disk is placed upon it a strip of manila paper is wrapped about and beyond its upper end and secured in such manner as to form a container for the charge of the explosive to be fired. The cylinder is then placed upon the anvil or rigid support; the 100-gram (3.5-ounce) charge of the explosive to be tested is placed in the container on the upper end of the lead cylinder in such a manner as to preserve the specific gravity found for it in the cartridges in which it is offered for use; a No. 7 electric detonator is embedded centrally in the top of the charge of explosive; and, without tamping, the charge is fired. The height of the lead cylinder after the firing is then determined with precision, and this height subtracted from the height of the cylinder before the trial gives the compression caused by the explosion. This result is considered a measure of the relative percussive force of the explosive.

Plate VII, A, illustrates an unused cylinder and disk and cylinders showing the various degrees of compression produced by different explosives.

THE TRAUZL LEAD BLOCKS.

The Trauzl test measures the comparative disruptive power of explosives when fired under moderate confinement. In making the test, equal weights of different explosives are confined in bore holes of definite dimensions, made in lead blocks of prescribed character, by means of a fixed quantity of stemming and when thus confined are exploded by means of similar detonators. In this test every effort is made to have each factor alike, except the character of the explosives which are being compared. The measure of the test is the volume by which the cavity in the block is increased because of the pressure exerted by the explosion under the degree of confinement to which the explosive is subjected by the quantity of stemming used, and the firmness with which this stemming is tamped.

Cylindrical lead blocks 200 millimeters (7.87 inches) in diameter and 200 millimeters (7.87 inches) in height are used. A bore hole 25

A. SMALL LEAD BLOCKS. A, BLOCK BEFORE TEST: B, C, D, E, F, BLOCKS AFTER TEST, SHOWING EFFECT OF DIFFERENT EXPLOSIVES.
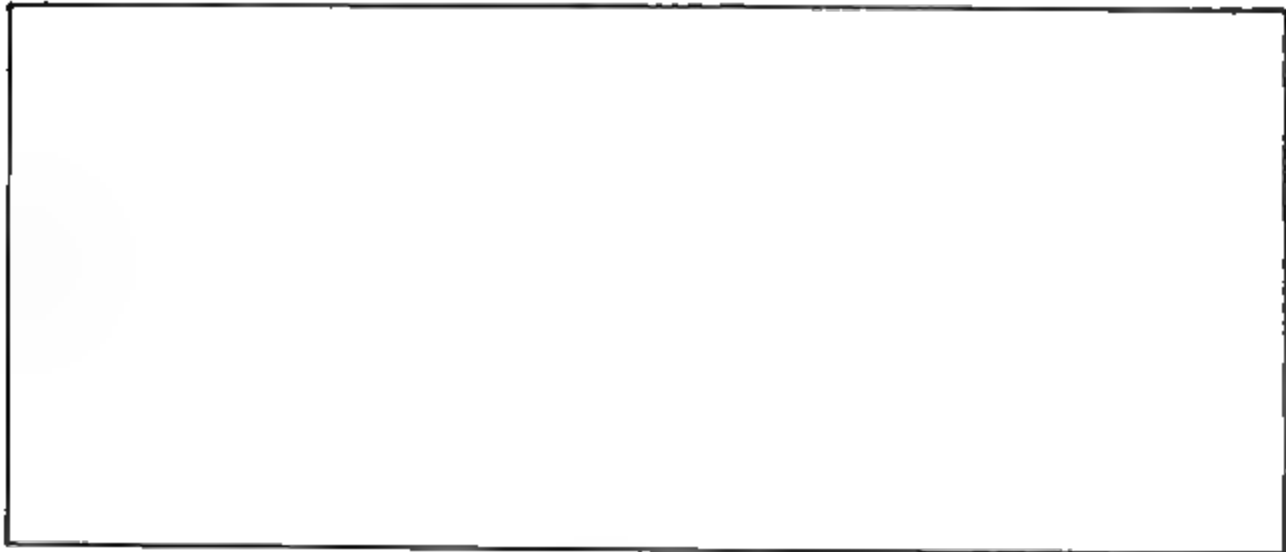
B. TRAUZL LEAD BLOCK AFTER TEST, AND SECTION SHOWING EXPANSION OF CAVITY BY EXPLOSIVE.

C. MINIATURE BLACK POWDER SEPARATOR.

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millimeters (0.98 inch) in diameter and 125 millimeters (4.92 inches) in depth is made centrally in the upper part of each block. The blocks are cast from desilverized lead of the best quality. Those used in the tests recorded in this bulletin were all made from one mold and the same kind of lead, and were cast under identical conditions, so that the well-known variations which occur in lead from different sources and as cast under different conditions were eliminated.

The material used in stemming was Lake Michigan dune sand containing only a trace of moisture and of such fineness that it passed through a 30-mesh screen and was caught on an 80-mesh screen. Fifty cubic centimeters (3.05 cubic inches) of this sand was used in each test.

The tamping of this stemming is effected by means of an automatic tamping device which operates on the principle of an automatic center punch. The tamping rod used has an area of 284 square millimeters (0.44 square inch). The hammer weighs 470 grams (16.56 ounces) and is actuated through a distance of 285 millimeters (11.22 inches) by a spiral brass spring having an initial tension of 12.7 kilograms (27.94 pounds). This spring is of 10-gage wire (English standard). It has an outside diameter of 52.5 millimeters (2.07 inches), a height of 111 millimeters (4.37 inches), and is coiled in six turns.

Since other investigators in making the Trauzl test have employed plates and yokes of iron with which to further confine the charge, attention is called to the fact that these have not been used at the Pittsburgh testing station. In the preliminary trials it was found that in placing a yoke the charge and stemming were more or less disturbed, and that therefore the initial conditions were not uniform.

METHOD OF CONDUCTING TEST.

The bore hole in the lead cylinder to be used is precisely measured by means of water so as to ascertain its volume in cubic centimeters and cubic inches.

The explosive is carefully removed from its cartridge or container, especial care being taken when the explosive is packed in a paraffined case that no paraffin is mixed with the explosive. A charge of 10 grams (154 grains), weighed on a chemical balance, is used, and this is wrapped in a piece of tin-foil so as to make a cartridge 25 millimeters (0.98 inch) in diameter and about 20 millimeters (0.79 inch) in height, varying with the density of the explosive. The pieces of tin-foil used as wrappers are trapezoidal in shape, the sides having lengths of 150 and 130 millimeters (5.9 and 5.1 inches) and the width being 70 millimeters (2.8 inches). A No. 7 electric detonator is placed in the center of this charge within the wrapper, and the whole is inserted in the bore hole of a lead cylinder. Forty cubic centimeters (2.44 cubic inches) of the dry sand are poured into the bore hole, carefully disposed about

the legs of the detonator, and tamped by 10 blows with the tamping device. Then 10 cubic centimeters (0.61 cubic inches) more of the sand is poured in and tamped with 40 blows from the tamping device. The loaded block is then placed on a rigid support, the temperature is noted to make sure that the temperature of the lead block is 15° C. (77° F.), and the charge is fired. The cavity in the block is then measured with water from a calibrated burette, as before, and thus the increase in volume is ascertained with precision.

The increase in the size of the cavity in a lead block is due to the combined effects of the exploding detonator and the exploding charge. As it has been found that the No. 7 electric detonator when fired in these blocks, surrounded only by dry sand tamped as described, increases the volume by 5 cubic centimeters (0.31 cubic inch), the effect of the detonator may be readily eliminated from the data given.

The appearance of lead blocks after firing is shown in Plate VII, B.

THE BLASTING-POWDER SEPARATOR.

The blasting-powder separator (Pl. VII, C) is used in determining the relative proportions of different sized grains in the black blasting powders supplied for use in coal mines. It is similar in form and construction to those used in some mills for grading the grains of powder. In constructing the device care was exercised to introduce no steel or iron parts which might come in contact with the powder.

The apparatus consists of a rectangular wooden box 6 feet 10 inches long, mounted at an angle of 9° from the horizontal on a wooden trestle. The box is provided with a series of slots on its inner sides, into which screens may be slipped. The screens are inserted at the upper end of the box. A wooden hopper, in the form of an inverted truncated pyramid 10 inches (25.4 centimeters) deep, 12 by 16 inches (30.5 by 40.6 centimeters) on the base, and having an aperture 3.5 by 1¼ inches (8.9 by 3.2 centimeters), is mounted on the upper end of the box above the set of screens, the top of the hopper being about 6½ feet (1.98 meters) above the floor. It is provided with a sliding brass apron to regulate the feed.

At the lower end of the inclined wooden box is a series of vertical wooden conduits, each being connected at its upper opening to one of the screens. Alongside these vertical conduits and below them is a series of wooden bins, in which the separated powder grains are received. Each vertical conduit is connected by an inclined lateral conduit to one of these bins. Each bin is provided with a sliding gate on the side, near the bottom, so that the grains collected in the bin may be removed.

A rod, with a crank on its end, is mounted on the side of the frame just below the inclined wooden box, and this rod is connected to the box by means of an eccentric device which, when the crank

is turned, causes the box with its contents to move to and fro laterally. By this means the powder is so shaken as to spread the grains out on the screens, cause them to pass through such screens as their sizes permit, and force them, when they can not pass through a screen, to travel down it, and, by the proper conduit, into the proper bin.

The screens consist of light wooden frames, to the bottoms of which are attached the meshed material. The bottoms of the screens having the coarse meshes consist of diagonally perforated zinc plates. The mesh numbers of each of the different zinc plates, perforated with circular holes, together with the diameters of the holes and the numbers of holes per square foot for each mesh number, are set forth in the following table:

Relation between sizes of black blasting powder and separating sieve.

Size of grains.	Diameter of round holes in screens through which grains pass.	Diameter of round holes in screens on which grains collect.
CCC	inch.	inch.
CC	inch.	inch.
C	inch.	inch.
F	inch.	inch.
FF	inch.	inch.
FFF	inch.	inch.
FFFF	inch.	*a* inch.

a Or 28-mesh bolting cloth.

In operating the device a weighed quantity of the powder is poured into the hopper. The sliding brass apron is then set to obtain the desired feed, and the crank is turned until the powder is all separated and the different-sized grains gathered in the different bins. The powder from each bin is then weighed separately. Obviously, all or as many of the screens as desired may be used in any given test.

RATE OF BURNING OF SLOW EXPLOSIVES.

The test for rate of burning of slow explosives is performed under the same conditions as the rate-of-detonation test in that the cartridge file is suspended in the pit outside of building No. 17, the lead wires to the electric detonator and to the copper interrupter wires which pass transversely through the explosive are connected in the same way; and also in that the Mettegang recorder is used to record the time interval.

The explosive is placed in a hydraulic pipe having an inside diameter of $1\frac{1}{2}$ inches, one end of which is filled for 4 inches and the other for 1 inch with plaster of Paris. The latter end is the one that accommodates the electric igniter or electric detonator.

The copper interrupter wires are placed 1 meter apart.

Care is taken that the density of the explosive is normal.

CHAPTER V.

RESULTS OF TESTS WITH PERMISSIBLE EXPLOSIVES.

By CLARENCE HALL and S. P. HOWELL.

ÆTNA COAL POWDER A.

Explosive, Ætna coal powder A.

Class, nitroglycerin.

Manufactured by the Ætna Powder Co.

Physical examination:

- Diameter of cartridge, 1½ inches.

  Length of cartridge, 8 inches.

  Average weight, 205 grams.

  Cartridge had not been redipped.

  Apparent specific gravity of cartridge by sand, 1.24.

  Color of explosive, buff.

  Consistency, mixed fibrous and granular; moderately cohesive.

Unit deflective charge as determined by the ballistic pendulum:

  Date: May 10, 1909.

  Unit swing on this date, 2.86 inches.

  Weight of charge, in grams, 300, 300, 300

  Swing, in inches, 3.07, 3.09, 3.14.

  Average swing, in inches, 3.10.

$$3.10 : 2.86 : : 300 : (277).$$

Therefore the unit deflective charge of Ætna coal powder A is 277 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				**TEST 3.**			
	Grams.	*Per cent.*			*Grams.*	*Per cent.*	
May 10.........	277	8.23	No ignition.	May 14.........	277	....	No ignition.
Do.........	277	8.23	Do.	Do.........	277	....	Do.
Do.........	277	8.27	Do.	Do.........	277	....	Do.
Do.........	277	8.26	Do.	Do.........	277	....	Do.
Do.........	277	8.15	Do.	Do.........	277	....	Do.
Do.........	277	8.05	Do.	Do.........	277	....	Do.
May 11.........	277	8.03	Do.	Do.........	277	....	Do.
Do.........	277	8.14	Do.	Do.........	277	....	Do.
Do.........	277	8.14	Do.	Do.........	277	....	Do.
Do.........	277	7.96	Do.	Do.........	277	....	Do.
TEST 2.				**TEST 4.**			
May 11.........	277	4.24	No ignition.	May 13.........	¹ 680	4.12	No ignition.
Do.........	277	4.18	Do.	Do.........	¹ 680	4.21	Do.
Do.........	277	4.15	Do.	Do.........	¹ 680	4.12	Do.
Do.........	277	4.05	Do.	May 14.........	¹ 680	4.05	Do.
Do.........	277	4.05	Do.	Do.........	¹ 680	4.12	Do.
Do.........	277	4.05	Do.				
Do.........	277	4.05	Do.	**TEST 5.**			
Do.........	277	4.05	Do.				
Do.........	277	4.30	Do.	May 14.........	ª 680	2.11	No ignition.
Do.........	277	4.12	Do.				

ª 680 grams or more was used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 7.

Date (1909).	Distance. between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
May 11	11.15	43	3,857
May 12	11.20	43	3,839

Average rate of detonation, 3,848 meters (12,620 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
May 22	22.00	27.79	8.75	0.438
Do	21.50	27.15	9.50	.475
Do	22.00	27.79	9.00	.450

Average height of flame, 27,58 inches.
Average duration of flame, 0.454 milliseconds.

IMPACT TEST.

Date, June 29, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
15	1	No explosion.	28	1	Explosion.
20	1	......do..........	27	3	No explosion.
25	1	......do..........	27	1	Explosion.
30	1	Explosion.	26	5	No explosion.

The maximum height at which no explosion occurs established at 26 centimeters (10.24 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 205 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
June 12	6	Exploded.	June 19	7	Did not explode.
Do	8	Did not explode.	Do	7	. Do.
Do	7	Do.			

The minimum distance at which no explosion occurs established at 7 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME, AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0. 4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
June 9	200	1.30	28.00	70.00	A	
Do	200	1.30	28.50	71.25	A	70.42
Do	200	1.30	28.00	70.00	A	
June 17	200	1.26	26.50	66.25	B	
Do	200	1.22	26.50	66.25	B	66.56
June 18	200	1.22	26.88	67.20	B	
Do	200	1.22	26.25	65.62	C	
Do	200	1.22	25.00	62.50	C	64.17
Do	200	1.22	25.75	64.38	C	

P=1.911A+0.5B−1.411C=77.31 kilos per square centimeter.

V=15,000 cubic centimeters.   S=1.24.   W=200 grams.

$M = \dfrac{VPS}{W} = 7{,}190$ kilograms per square centimeter (102,259 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 26, 1909.

	Grams.
Solid	57. 2
Liquid (water)	14. 0
Gaseous	116. 8

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	*°C.*	*Calories.*
June 23	82.13	0.823	762.4
June 24	82.13	.786	727.7
Do	82.13	.783	724.9

Average large calories per kilogram of explosive, 738.3.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
May 11	63.5	47.0	16.5
Do	63.5	48.2	15.3
Do	63.5	47.2	16.3

Average compression, 16.0 millimeters (0.63 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	*Cubic centimeters.*	*Cubic centimeters.*	*°C.*
June 29	62	286	224	20
Do	62	284	222	20
July	62	295	233	25

Average expansion of bore hole, 226 cubic centimeters (13.79 cubic inches).

ÆTNA COAL POWDER B.

Explosive: Ætna coal powder B.

Class: Nitroglycerin.

Manufactured by the Ætna Powder Co.

Physical examination:

Diameter of cartridge, 1½ inches.

Length of cartridge, 8 inches.

Average weight, 300 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 1.10.

Color of explosive, light-buff.

Consistency, mixed fibrous and granular; moderately cohesive.

Unit deflective charge as determined by the ballistic pendulum:

Date, May 10, 1909.

Unit swing on this date, 2.86 inches.

Weight of charge, in grams, 290, 290, 290

Swing, in inches, 2.81, 2.74, 2.73.

Average swing, in inches, 2.76.

2.76 : 2.86 : 290 : (301).

Therefore the unit deflective charge of Ætna coal powder B is 301 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				**TEST 3.**			
	Grams.	*Per cent.*			*Grams.*	*Per cent.*	
May 11	301	8.27	No ignition.	May 14	301		No ignition.
Do	301	8.00	Do.	Do	301		Do.
Do	301	8.15	Do.	Do	301		Do.
May 12	301	8.00	Do.	Do	301		Do.
Do	301	8.00	Do.	Do	301		Do.
Do	301	8.00	Do.	May 17	301		Do.
Do	301	8.15	Do.	Do	301		Do.
Do	301	8.15	Do.	Do	301		Do.
Do	301	8.15	Do.	Do	301		Do.
Do	301	8.07	Do.	Do	301		Do.
TEST 2.				**TEST 4.**			
May 12	301	4.21	No ignition.	May 13	a 680	4.17	No ignition.
Do	301	4.12	Do.	Do	a 680	4.05	Do.
Do	301	4.12	Do.	Do	a 680	3.95	Do.
Do	301	4.12	Do.	Do	a 680	4.05	Do.
Do	301	4.05	Do.	Do	a 680	4.12	Do.
Do	301	4.05	Do.				
Do	301	3.88	Do.	**TEST 5.**			
Do	301	4.05	Do.				
Do	301	4.05	Do.	May 13	a 680	2.20	No ignition.
Do	301	4.12	Do.				

a 680 grams or more were used.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 7.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
May 13...	14.00	43	3,071
May 14...	14.60	43	2,945

Average rate of detonation, 3,008 meters (9,870 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
June 11...	22.50	28.42	10.50	0.525
Do...	22.00	27.79	8.25	.412
Do...	21.50	27.15	9.50	.475

Average height of flame, 27.79 inches.
Average duration of flame, 0.471 milliseconds.

IMPACT TEST.

Date, June 29, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
20	1	Explosion.	18	1	Explosion.
15	1	No explosion.	17	1	No explosion.
18	1	Do.	17	1	Explosion.
19	1	Explosion.	16	5	No explosion.

The maximum height at which no explosion occurs established at 16 centimeters (6.30 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 208 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
June 21............	6	Did not explode.	June 21........	5	Did not explode.
Do...........	4	Exploded.	Do........	5	Do.
Do...........	5	Did not explode.			

The minimum distance at which no explosion occurs established at 5 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
June 9	200	1.22	26.88	67.20	A	
Do	200	1.22	26.75	66.88	A	66.78
Do	200	1.22	26.50	66.25	A	
June 18	200	1.18	25.00	62.50	B	
Do	200	1.18	25.00	62.50	B	62.71
Do	200	1.18	25.25	63.12	B	
Do	200	1.18	24.75	61.88	C	
June 19	200	1.18	24.75	61.88	C	61.88
Do	200	1.18	24.75	61.88	C	

P=1.911A+0.5B−1.411C=71.66 kilograms per square centimeter.

V=15,000 cubic centimeters.   S=1.10.   W=200 grams.

$M=\frac{VPS}{W}$=5,912 kilograms per square centimeter (84,083 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 27, 1909.

Grams.

Solid 65.1

Liquid (water) 15.4

Gaseous 103.9

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	*°C.*	*Calories.*
June 24	82.13	0.820	759.6
Do	82.13	.825	764.3
June 25	82.13	.818	757.7

Average large calories per kilogram of explosive, 760.5

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
May 11	63.5	49.5	14.0
Do	63.5	49.8	13.7
Do	63.5	49.8	13.7

Average compression, 13.8 millimeters (0.54 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	*Cubic centimeters.*	*Cubic centimeters.*	*° C.*
June 29	62	248	186	29
Do	62	254	192	29
July 28	62	268	206	25

Average expansion of bore hole, 195 cubic centimeters (11.90 cubic inches).

CARBONITE NO. 1.

Explosive, Carbonite No. 1.

Class, nitroglycerin.

Manufactured by E. I. Du Pont de Nemours Powder Co.

Physical examination:

> Diameter of cartridge, 1½ inches.
>
> Length of cartridge, 8 inches.
>
> Average weight, 300 grams.
>
> Cartridge had not been redipped.
>
> Apparent specific gravity of cartridge by sand, 1.33.
>
> Color of explosive, drab.
>
> Consistency, granular, moderately cohesive.

Unit deflective charge as determined by the ballistic pendulum:

> Date, February 4, 1909.
>
> Unit swing on this date, 3.01 inches.
>
> Weight of charge, in grams, 260, 260, 260.
>
> Swing, in inches, 3.08 3.04, 2.95.
>
> Average swing, in inches, 3.02.

$$3.02 : 3.01 : : 260 : (259).$$

Therefore the unit deflective charge of Carbonite No. 1 is 259 grams.

GAS AND DUST GALLERY No. 1

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	*Per cent.*			*Grams.*	*Per cent.*	
Feb. 9	259	7.98	No. ignition.	Feb. 6	259		No ignition.
Do	259	7.97	Do.	Do	259		Do.
Do	259	7.85	Do.	Do	259		Do.
Do	259	8.37	Do.	Do	259		Do.
Do	259	8.17	Do.	Do	259		Do.
Do	259	8.09	Do.	Do	259		Do.
Do	259	8.14	Do.	Do	259		Do.
Feb. 10	259	8.02	Do.	Feb. 10	259		Do.
Do	259	8.01	Do.	Do	259		Do.
Do	259	8.08	Do.	Do	259		Do.
TEST 2.				TEST 4.			
Feb. 5	259	4.02	No ignition.	Mar. 2	a 680	4.10	No ignition.
Do	259	3.95	Do.	Do	a 680	3.93	Do.
Do	259	3.94	Do.	Do	a 680	4.03	Do.
Do	259	3.95	Do.	Do	a 680	3.93	Do.
Do	259	4.02	Do.	Do	a 680	4.18	Do.
Do	259	4.09	Do.				
Feb. 6	259	4.09	Do.	TEST 5.			
Do	259	4.41	Do.				
Do	259	4.08	Do.	Mar. 5	a 680	2.01	No ignition.
Do	259	4.15	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
Mar. 20	12.63	43	3,405
Mar. 23	13.15	43	3,270

Average rate of detonation, 3,338 meters (10,950 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
Mar. 12	20.12	25.41	8.50	0.425
Mar. 19	19.75	24.95	8.62	.431
Do	19.50	24.63	9.25	.462

Average height of flame, 24.99 inches.
Average duration of flame, 0.439 milliseconds.

IMPACT TEST.

Date, February 5 and 6, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
20	1	Explosion.	15	1	Explosion.
15	1	No explosion.	14	2	No explosion.
18	1	Explosion.	14	1	Explosion.
17	3	No explosion.	13	1	Do.
17	1	Explosion.	12	1	Do.
16	1	Do.	11	1	Do.
15	1	No explosion.	10	5	No explosion.

The maximum height at which no explosion occurs established at 10 centimeters (3.94 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 215 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
Mar. 23	5	Exploded.	Mar. 25	10	Did not explode.
Do	5	Do.	Do	9	Do.
Do	7	Do.	Do	9	Do.
Do	8	Do.	Do	9	Do.

The minimum distance at which no explosion occurs established at 9 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Aver ge pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
Feb. 11	100	1.22	19.50	34.82	A	
Do	100	1.22	18.50	33.03	A	33.92
Do	100	1.22	19.00	33.92	A	
Mar. 22	100	1.18	16.00	28.57	B	
Do	100	1.18	16.50	29.46	B	29.16
Do	100	1.18	16.50	29.46	B	
Do	100	1.18	14.75	26.34	C	
Mar. 23	100	1.22	15.50	27.68	C	27.08
Do	100	1.22	15.25	27.23	C	

P=1.911A+0.3B−1.411C=41.19 kilograms per square centimeter.

V=15,000 cubic centimeters. S=1.33. W=100 grams.

$M=\dfrac{VPS}{W}$=8,217 kilograms per square centimeter (116,865 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 4, 1909.

Grams.

Solid 59.1
Liquid (water) 11.7
Gaseous 113.5

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	*°C.*	*Calories.*
Mar. 16	83.00	0.817	763.9
Do	82.68	.850	792.4
Mar. 25	81.90	.816	754.0

Average large calories per kilogram of explosive, 770.1.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
Feb. 5	64.0	49.5	14.5
Feb. 6	64.0	50.0	14.0
Do	64.0	49.5	14.5

Average compression, 14.3 millimeters (0.56 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Tempera- ture of block.
	Before shot.	After shot.		
Oct. 16	*Cubic c. c.* 62	*Cubic c. c.* 222	*Cubic c. c.* 160	*° C.* 15
Do	62	226	164	15
Do	62	218	156	15

Average expansion of bore hole, 160 cubic centimeters (9.76 cubic inches).

CARBONITE NO. 2.

Explosive, Carbonite No. 2.

Class, nitroglycerin.

Manufactured by E. I. Du Pont de Nemours Powder Co.

Physical examination:

Diameter of cartridge, 1¼ inches.

Length of cartridge, 8 inches.

Average weight, 237 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 0.98.

Color of explosive, light-drab.

Consistency, fibrous, slightly cohesive.

Unit deflective charge as determined by the ballistic pendulum:

Date, February 19, 1909.

The unit swing used on this date is 3.01 inches.

Weight of charge, in grams, 300, 300, 300.

Swing, in inches, 2.98, 2.95, 3.04.

Average swing, in inches, 2.99.

$$2.99 : 3.01 : : 300 : (302).$$

Therefore the unit deflective charge of Carbonite No. 2 is 302 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				**TEST 3.**			
	Grams.	*Per cent.*			*Grams.*	*Per cent.*	
Feb. 9	307	7.91	No ignition.	Feb. 5	307		No ignition.
Do	307	8.49	Do.	Do	307		Do.
Do	307	8.10	Do.	Do	307		Do.
Do	307	8.11	Do.	Do	307		Do.
Do	307	7.91	Do.	Do	307		Do.
Do	307	7.90	Do.	Do	307		Do.
Do	307	7.90	Do.	Do	307		Do.
Do	307	7.82	Do.	Do	307		Do.
Feb. 10	307	7.99	Do.	Do	307		Do.
Feb. 19	307	8.18	Do.	Do	307		Do.
TEST 2.				**TEST 4.**			
Feb. 5	307	5.03	No ignition.	Feb. 12	*a* 680	4.01	No ignition.
Do	307	4.87	Do.	Do	*a* 680	4.00	Do.
Do	307	4.07	Do.	Do	*a* 680	3.94	Do.
Do	307	3.97	Do.	Do	*a* 680	3.78	Do.
Do	307	4.02	Do.	Do	*a* 680	3.90	Do.
Do	307	3.97	Do.				
Do	307	4.09	Do.	**TEST 5.**			
Do	307	4.09	Do.				
Do	307	4.05	Do.	Mar. 4	*a* 680	2.01	No ignition.
Do	307	4.14	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches
Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
Mar. 18	12.22	43	3,519
Mar. 19	12.57	43	3,421

Average rate of detonation, 3,470 meters (11,380 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Millisecond.*
Mar. 12	15.00	18.96	6.75	0.338
Mar. 19	17.00	21.47	7.25	.362
Do.	17.25	21.79	6.50	.325

Average height of flame, 20.74 inches.
Average duration of flame, 0.342 millisecond.

IMPACT TEST.
Date, March 6 and 8, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
20	1	No explosion.	20	1	Explosion.
25	1	Do.	19	1	Do.
30	1	Explosion.	17	1	No explosion.
29	1	Do.	17	1	Explosion.
28	1	Do.	16	1	Do.
27	1	Do.	15	1	Do.
26	1	Do.	14	3	No explosion.
25	1	Do.	14	1	Explosion.
24	1	Do.	13	5	No explosion.
23	1	Do.			

The maximum height at which no explosion occurs is established at 13 centimeters (5.12 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 170 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
Mar. 19	4	Exploded.	Mar. 22	6	Did not explode.
Do.	6	Did not explode.	Do.	5	Do.
Mar. 22	5	Exploded.			

The minimum distance at which no explosion occurs is established at 6 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeters=1 kilogram per square centimeter—

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
Feb. 10	100	0.98	19.20	34.28	A	
Feb. 11	100	.98	19.00	33.92	A	33.74
Do	100	.98	18.50	33.03	A	
Mar. 18	100	.98	16.30	29.11	B	
Do	100	.98	16.50	29.46	B	29.34
Do	100	.98	16.50	29.46	B	
Do	100	.98	15.00	26.79	C	
Do	100	.98	15.25	27.23	C	27.08
Do	100	.98	15.25	27.23	C	

P=1.911A+0.5B−1.411C=40.94 kilograms per square centimeter.

V=15,000 cubic centimeters. S=0.98. W=100 grams.

$M=\dfrac{VPS}{W}$=6,018 kilograms per square centimeter (85,590 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 5, 1909.   Grams.

Solid... 57.5

Liquid (water)... 12.0

Gaseous... 114.7

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	*°C.*	*Calories.*
Feb. 23	81.60	0.751	691.0
Do	81.42	.776	712.8
Feb. 24	81.30	.797	731.4

Average large calories per kilogram of explosive, 711.7.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
Feb. 16	64.0	51.0	13.0
Do	64.0	50.8	13.2
Do	64.0	50.8	13.2

Average compression, 13.1 millimeters (0.52 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Tempera- ture of block.
	Before shot.	After shot.		
	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.	°C.
Oct. 16	62	247	185	15
Do	62	246	184	15
Do	62	244	182	15

Average expansion of bore hole, 184 cubic centimeters (11.22 cubic inches).

CARBONITE NO. 3.

Explosive, Carbonite No. 3.

Class, nitroglycerin.

Manufactured by E. I. du Pont de Nemours Powder Co.

Physical examination:

Diameter of cartridge, 1½ inches.

Length of cartridge, 8 inches.

Average weight, 235 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 1.00.

Color of explosive, light cafe-au-lait.

Consistency, dry, fibrous.

Unit deflective charge as determined by the ballistic pendulum:

Date, February 24, 1909.

Unit swing used on this date, 3.01 inches.

Weight of charge, in grams, 330, 330, 330.

Swing, in inches, 3.02, 3.05, 3.10.

Average swing, in inches, 3.06.

3.06: 3.01: : 330: (325).

Therefore the unit deflective charge of Carbonite No. 3 is 325 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	Per cent.			Grams.	Per cent.	
Feb. 19	331	8.35	No ignition.	Feb. 1	325		No ignition.
Feb. 27	324	8.20	Do.	Do	325		Do.
Do	324	8.20	Do.	Feb. 2	325		Do.
Do	324	7.86	Do.	Do	325		Do.
Do	324	7.92	Do.	Do	325		Do.
Do	324	7.92	Do.	Do	325		Do.
Mar. 1	324	8.13	Do.	Do	325		Do.
Do	324	8.09	Do.	Do	325		Do.
Do	324	8.16	Do.	Do	325		Do.
Do	324	8.12	Do.	Do	325		Do.
TEST 2.				TEST 4.			
Feb. 1	325	4.08	No ignition.	Mar. 4	a 680	3.88	No ignition.
Do	325	3.89	Do.	Do	a 680	3.80	Do.
Do	325	4.04	Do.	Do	a 680	3.82	Do.
Do	324	3.85	Do.	Do	a 680	4.13	Do.
Do	325	4.01	Do.	Do	a 680	4.00	Do.
Do	325	4.13	Do.				
Do	325	4.09	Do.	TEST 5.			
Do	325	4.08	Do.				
Do	325	4.02	Do.	Mar. 5	a 680	2.01	No ignition.
Do	325	4.13	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
Mar. 11	16.33	43	2,633
Mar. 12	16.05	43	2,679

Average rate of detonation, 2,656 meters (8,710 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
Mar. 11	14.25	18.00	6.62	0.331
Do	14.00	17.68	6.50	.325
Mar. 16	12.50	15.79	6.50	.325

Average height of flame, 17.16 inches.
Average duration of flame, 0.327 milliseconds.

IMPACT TEST.

Date, February 1, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
20	1	No explosion.	22	1	Explosion.
25	2	Explosion.	21	1	Do.
23	1	Do.	20	4	No explosion.

The maximum height at which no explosion occurs is established at 20 centimeters (7.87 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 173 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
Mar. 15	8	Did not explode.	Mar. 17	3	Did not explode.
Mar. 16	6	Do.	Do	3	Do.
Do	4	Do.	Mar. 18	3	Do.
Do	2	Exploded.			

The minimum distance at which no explosion occurs is established at 3 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeters=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
Feb.9	100	0.93	16.75	29.91	A	} 29.17
Do	100	.98	16.25	29.02	A	
Feb.10	100	.98	16.00	28.57	A	
Mar.16	100	1.03	15.00	26.73	B	} 26.93
Do	100	1.03	15.25	27.23	B	
Do	100	1.03	15.00	26.73	B	
Do	100	1.03	14.68	26.21	C	} 25.55
Feb.17	100	1.03	14.00	25.00	C	
Do	100	1.03	14.25	25.45	C	

$P = 1.911A + 0.5B - 1.411C = 33.16$ kilograms per square centimeter.

$V = 15,000$ cubic centimeters. $S = 1.00.$ $W = 100$ grams.

$M = \dfrac{VPS}{W} = 4,974$ kilograms per square centimeter (70,742 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, April 27, 1909.

Grams.
Solids 75.5
Liquid (water) 12.1
Gaseous 102.3

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Development per kilogram.
	Kilograms.	*°C.*	*Calories.*
Feb.12	80.00	0.783	708.2
Do	80.30	.770	698.6
Do	80.25	.783	710.2

Average large calories per kilogram of explosive, 705.7.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
Feb.1	64.0	53.5	10.5
Do	64.0	53.0	11.0
Do	64.0	53.0	11.0

Average compression, 10.8 millimeters (0.43 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCK.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	*Cubic centimeters.*	*Cubic centimeters.*	*° C.*
Oct. 16	62	218	156	15
Do	62	220	158	15
Do	62	216	154	15

Average expansion of bore hole, 156 cubic centimeters (9.52 cubic inches).

CARBONITE NO. 1 L. F.

Explosive, Carbonite No. 1 L. F.

Class, nitroglycerin.

Manufactured by the E. I. du Pont de Nemours Powder Co.

Physical examination:

Diameter of cartridge, $1\frac{1}{4}$ inch.

Length of cartridge, 8 inches.

Average weight, 305 grams.

Cartridge has been redipped in paraffine.

Apparent specific gravity of cartridge by sand, 1.35.

Color of explosive, cafe-au-lait.

Consistency, granular, moderately cohesive.

Unit deflective charge, as determined by the ballistic pendulum:

Date, February 17, 1909.

Unit swing used on this date, 3.01 inches.

Weight of charge, in grams, 300, 300, 300.

Swing, in inches, 2.97, 3.035, 2.96.

Average swing in inches, 2.99.

2.99:3.01::300:(302).

Therefore the unit deflective charge of Carbonite No. 1 L. F. is 302 grams.

GAS AND DUST GALLERY No. 1.

Date (1909.)	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				**TEST 3.**			
	Grams.	*Per cent.*			*Grams.*	*Per cent.*	
Feb. 16	330	7.82	No ignition.	Feb. 18	302		No ignition.
Do	330	7.75	Do.	Do	302		Do.
Do	330	7.94	Do.	Do	302		Do.
Do	330	7.88	Do.	Do	302		Do.
Do	330	7.77	Do.	Do	302		Do.
Do	330	7.92	Do.	Do	302		Do.
Do	330	7.87	Do.	Do	302		Do.
Feb. 17	330	7.74	Do.	Do	302		Do.
Do	330	8.11	Do.	Do	302		Do.
Do	330	7.82	Do.	Do	302		Do.
TEST 2.				**TEST 4.**			
Feb. 17	302	3.96	No ignition.	Feb 19	a 680	5.14	No ignition.
Do	302	4.11	Do.	Do	a 680	4.06	Do.
Feb. 18	302	4.01	Do.	Do	a 680	3.99	Do.
Do	302	3.96	Do.	Feb. 20	a 680	4.16	Do.
Do	302	4.06	Do.	Do	a 680	3.92	Do.
Do	302	4.05	Do.				
Do	302	3.96	Do.	**TEST 5.**			
Do	302	4.01	Do.				
Do	302	4.01	Do.	Mar. 5	a 680	2.01	No ignition.
Do	302	4.02	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
Mar. 27..	26.81	43	1,604
Mar. 30..	25.68	43	1,674

Average rate of detonation, 1,639 meters (5,380 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Millisecond.*
Mar. 12...	12.62	15.94	5.88	0.294
Do...	11.75	14.84	5.12	.256
Do...	11.88	14.87	4.38	.219

Average height of flame, 15.05 inches.
Average duration of flame, 0.256 milliseconds.

IMPACT TEST.

Date, February 20, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
20	1	No explosion.	21	1	Explosion.
25	1	Explosion.	20	1	Do.
24	1	Do.	19	1	Do.
23	1	Do.	18	1	Do.
22	1	No explosion.	17	5	No explosion.
22	1	Explosion.			

The maximum height at which no explosion occurs established at 17 centimeters (6.69 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 213 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
Mar. 27..........	8	Did not explode.	Mar. 29..........	4	Exploded.
Mar. 29..........	6	Do.	Do..........	5	Did not explode.
Do..........	4	Do.	Mar. 30..........	5	Do.
Do..........	3	Exploded.	Do..........	5	Do.

The minimum distance at which no explosion occurs established at 5 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeters=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		Millimeters.	Kilograms.		Kilograms.
Feb. 16	100	1.26	16.00	28.57	A	
Do	100	1.26	16.50	29.46	A	28.99
Do	100	1.26	16.20	28.93	A	
Mar. 27	100	1.26	15.75	28.12	B	
Do	100	1.26	15.25	27.23	B	27.68
Mar. 29	100	1.26	15.50	27.68	B	
Do	100	1.26	14.75	26.34	C	
Do	100	1.26	15.00	26.78	C	26.64
Mar. 31	100	1.26	15.00	26.78	C	

P=1.911 A+0.5 B−1.411 C=31.65 kilograms per square centimeter.

V=15,000 cubic centimeters.   S=1.35.   W=100 grams.

$M=\dfrac{VPS}{W}=6,409$ kilograms per square centimeter (91,151 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 6, 1909.

	Grams.
Solid	62.8
Liquid (water)	10.4
Gaseous	116.5

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	°C.	Calories.
Mar. 27	83.38	0.725	679.6
Do	83.28	.727	680.8
Do	83.28	.747	699.8

Average large calories per kilogram of explosive, 686.7.

COMPRESSION OF SMALL LEAD BLOCKS.
Charge, 100 grams.

Date (1909).	Height—		Compression.
	Before explosion.	After explosion.	
	Millimeters.	Millimeters.	Millimeters.
Feb. 24	64.0	51.8	12.2
Do	64.0	51.8	12.2
Do	64.0	52.0	12.0

Average compression, 12.1 millimeters (0.48 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole—		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.	°C.
Oct. 16	62	215	153	15
Do	62	215	153	15
Do	62	215	153	15

Average expansion of bore hole, 153 cubic centimeters (9.33 cubic inches).

CARBONITE NO. 2 L. F.

Explosive, Carbonite No. 2 L. F.
Class, nitroglycerin.
Manufactured by E. I. Du Pont de Nemours Powder Co.
Physical examination:

Diameter of cartridge, 1½ inches.
Length of cartridge, 8 inches.
Average weight, 232 grams.
Cartridge had been redipped in paraffin.
Apparent specific gravity of cartridge by sand, 0.96.
Color of explosive, light-buff.
Consistency, mixed granular and fibrous; slightly cohesive.

Unit deflective charge as determined by the ballistic pendulum:

Date, February 18, 1909.
Unit swing used on this date, 3.01 inches.
Weight of charge, in grams, 310, 310, 310.
Swing, in inches, 3.01, 3.03, 3.13.
Average swing in inches, 3.06.

3.06:3.01::310:(305).

Therefore the unit deflective charge of Carbonite No. 2 L. F. is 305 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	Per cent.			Grams.	Per cent.	
Feb. 16	335	8.44	No ignition.	Feb. 18	335		No ignition.
Do	335	8.44	Do.	Do	305		Do.
Do	335	7.87	Do.	Do	305		Do.
Do	335	7.90	Do.	Do	305		Do.
Do	335	7.98	Do.	Do	305		Do.
Do	335	7.88	Do.	Do	305		Do.
Do	335	8.12	Do.	Do	305		Do.
Do	335	7.86	Do.	Do	305		Do.
Do	335	7.95	Do.	Do	305		Do.
Do	335	7.89	Do.	Do	305		Do.
TEST 2.				TEST 4.			
Feb. 17	335	4.02	No ignition.	Feb. 20	a 680	4.06	No ignition.
Do	335	4.06	Do.	Do	a 680	3.87	Do.
Do	335	4.03	Do.	Do	a 680	3.95	Do.
Do	335	4.05	Do.	Do	a 680	3.86	Do.
Do	335	3.96	Do.	Feb. 21	a 680	3.80	Do.
Do	335	4.01	Do.				
Do	335	3.96	Do.	TEST 5.			
Do	335	3.96	Do.				
Do	335	4.04	Do.	Mar. 5	a 680	2.10	No ignition.
Do	335	4.07	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
Mar. 31..	18.50	43	2,324
Apr. 1...	17.55	43	2,450

Average rate of detonation, 2,387 meters (7,830 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds*
Mar. 29..	12.25	16.74	5.38	0.269
Do...	15.38	19.43	6.50	.325
Do...	14.25	18.00	6.12	.306

Average height of flame, 18.05 inches.
Average duration of flame, 0.300 milliseconds.

IMPACT TESTS.

Date, February 23, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
20	1	No explosion.	24	5	No explosion.
25	1	Explosion.			

The maximum height at which no explosion occurs established at 24 centimeters (9.45 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 167 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
Mar. 30..........	4	Did not explode.	Apr. 2..........	1	Exploded.
Do..........	3	Do.	Do..........	2	Did not explode.
Apr. 1..........	2	Do.	Do..........	2	Do.

The minimum distance at which no explosion occurs established at 2 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeters = 1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
Feb. 17.................	100	0.93	16.50	29.46	A	
Do.................	100	.93	16.75	29.91	A	} 29.61
Do.................	100	.93	16.50	29.46	A	
Mar. 31.................	100	.93	13.75	24.55	B	
Apr. 1.................	100	.88	14.50	25.89	B	} 25.30
Apr. 2.................	100	.88	14.25	25.45	B	
Apr. 1.................	100	.84	13.60	24.29	C	
Do.................	100	.88	13.25	23.66	C	} 24.47
Do.................	100	.88	14.25	25.45	C	

P=1.911 A+0.5B−1.411C=34.71 kilograms per square centimeter.

V=15,000 cubic centimeters.   S=0.96.   W=100 grams.

$M = \dfrac{VPS}{W} = 4{,}998$ kilograms per square centimeter (71,084 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 6, 1909.

                                                                      Grams.
Solid 60.0
Liquid (water) 12.0
Gaseous 117.0

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	*°C.*	*Calories.*
Mar. 29.................	82.58	0.740	688.0
Do.................	82.43	.748	694.4
Do.................	82.29	.736	682.1

Average large calories per kilogram of explosive, 688.2.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
Feb. 24.................	64.0	53.2	10.8
Do.................	64.0	53.5	10.5
Do.................	64.0	53.5	10.5

Average compression, 10.6 millimeters (0.42 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	*Cubic centimeters.*	*Cubic centimeters.*	*°C.*
Apr. 3	62	214	152	15
Do	62	210	148	15
Do	62	207	145	15

Average expansion of bore hole, 148 cubic centimeters (9.03 cubic inches).

COAL SPECIAL NO. 1.

Explosive, Coal Special No. 1.
Class, nitroglycerin.
Manufactured by Keystone National Powder Co.
Physical examination:
Diameter of cartridge, 1¼ inches.
Length of cartridge, 8 inches.
Average weight, 199.5 grams.
Cartridge had been redipped in paraffin.
Apparent specific gravity of cartridge by sand, 1.14.
Color of explosive, cafe-au-lait.
Consistency, mixed granular and fibrous, moderately cohesive.
Unit deflective charge as determined by the ballistic pendulum:
Date, March 26, 1909.
Unit swing used on this date, 3.01 inches.
Weight of charge, in grams, 275, 275, 275.
Swing, in inches, 2.94, 2.85, 2.83.
Average swing, in inches, 2.87.

2.87:3.01::275:(288)

Therefore the unit deflective charge of Coal Special No. 1 is 288 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	*Per cent.*			*Grams.*	*Per cent.*	
Mar. 25	315	7.95	No ignition.	Mar. 26	315		No ignition.
Do	315	7.98	Do.	Do	315		Do.
Do	315	7.96	Do.	Do	315		Do.
Do	315	8.02	Do.	Do	315		Do.
Do	315	8.15	Do.	Do	315		Do.
Do	315	8.02	Do.	Do	315		Do.
Do	315	8.07	Do.	Do	315		Do.
Do	315	8.28	Do.	Do	315		Do.
Do	315	8.22	Do.	Do	315		Do.
Do	315	8.06	Do.	Do	315		Do.
TEST 2.				TEST 4.			
Mar. 25	315	3.90	No ignition.	Mar. 24	a 680	4.12	No ignition.
Do	315	3.81	Do.	Do	a 680	4.18	Do.
Do	315	3.97	Do.	Do	a 680	4.13	Do.
Do	315	4.07	Do.	Do	a 680	4.13	Do.
Do	315	4.14	Do.	Do	a 680	4.09	Do.
Mar. 26	315	4.15	Do.				
Do	315	4.84	Do.	TEST 5.			
Do	315	3.97	Do.				
Do	315	3.85	Do.	Apr. 8	a 680	2.02	No ignition.
Apr. 8	315	4.03	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
Apr. 23	11.90	43	3,613
Apr. 24	12.00	43	3,583

Average rate of detonation 3,598 meters (11,800 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
Apr. 27	18.50	23.37	8.00	0.400
Apr. 28	19.00	24.00	7.25	.362
Do	17.75	22.42	7.25	.362

Average height of flame, 23.26 inches.
Average duration of flame, 0.375 milliseconds.

IMPACT TESTS.

Date, May 7, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
15	1	No explosion.	15	1	Explosion.
20	1	Explosion.	14	3	No explosion.
19	1	Do.	14	1	Explosion.
18	1	Do.	13	1	No explosion.
18	1	No explosion.	13	1	Explosion.
17	1	Explosion.	12	5	No explosion.
16	1	Do.			

The maximum height at which no explosion occurs is established at 12 centimeters (4.72 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 205 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
May 8	6	Exploded.	May 8	11	Did not explode.
Do	8	Do.	May 10	11	Do.
Do	10	Do.	May 18	11	Do.
Do	12	Did not explode.			

The minimum distance at which no explosion occurs is established at 11 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeters=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
May 7	200	1. 21	28. 85	72. 12	A	
Do	200	1. 21	29. 25	73. 12	A	72. 37
Do	200	1. 21	28. 75	71. 88	A	
Do	200	1. 21	26. 75	66. 88	B	
Do	200	1. 21	26. 50	66. 25	B	66. 67
Do	200	1. 21	26. 75	66. 88	B	
Do	200	1. 21	25. 75	64. 38	C	
May 8	200	1. 21	25. 75	64. 38	C	63. 75
Do	200	1. 21	25. 00	62. 50	C	

$P=1.911A+0.5B-1.411$ $C=81.68$ kilograms per square centimeter.

$V=15,000$ cubic centimeters. $S=1.14.$ $W=200$ grams.

$M=\dfrac{VPS}{W}=69.84$ kilograms per square centimeter (99,329 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, April 19, 1909.

		Grams.
Solid		65. 8
Liquid (water)		13. 8
Gaseous		102. 4

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Per kilogram.
	Kilograms.	*°C.*	*Calories.*
Apr. 18	85. 18	0. 843	806. 8
Do	84. 98	. 858	819. 6
Apr. 20	82. 58	. 847	788. 7

Average large calories per kilogram of explosive, 805.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
Apr. 8	64. 0	48. 5	15. 5
Do	64. 0	48. 0	16. 0
Do	64. 0	48. 0	16. 0

Average compression, 15.8 millimeters (0.62 inch).

2406°—Bull. 15—12——10

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Tempera-ture of block.
	Before shot.	After shot.		
	Cubic centimeters.	*Cubic centimeters.*	*Cubic centimeters.*	*°C.*
Apr. 10	62	216	154	15
Do	62	212	150	15
Do	62	218	156	15

Average expansion of bore hole, 153 cubic centimeters (9.33 cubic inches).

COAL SPECIAL NO. 2.

Explosive, Coal Special No. 2.

Class, nitroglycerin.

Manufactured by Keystone National Powder Co.

Physical examination:

  Diameter of cartridge, 1¼ inches.

  Length of cartridge, 8 inches.

  Average weight, 209 grams.

  Cartridge had been redipped in paraffin.

  Apparent specific gravity of cartridge by sand, 1.12.

  Color of explosive, cafe-au-lait.

  Consistency, mixed granular and fibrous, moderately cohesive.

Unit deflective charge as determined by the ballistic pendulum:

  Date: March 27, 1909.

  Unit swing used on this date, 3.01 inches.

  Weight of charge in grams, 310,   310,   310.

  Swing, in inches, 3.07,   3.05,   3.09.

  Average swing, in inches, 3.07.

3.07:3.01::310:(304).

Therefore the unit deflective charge of Coal Special No. 2 is 304 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	*Per cent.*			*Grams.*	*Per cent.*	
Mar. 27	304	8.44	No ignition.	Apr. 7	304		No ignition.
Do.	304	8.42	Do.	Do	304		Do.
Mar. 28	304	7.76	Do.	Do	304		Do.
Do	304	7.66	Do.	Do	304		Do.
Do	304	8.09	Do.	Do	304		Do.
Do	304	8.07	Do.	Do	304		Do.
Do	304	7.92	Do.	Do	304		Do.
Do	304	7.92	Do.	Do	304		Do.
Do	304	8.61	Do.	Do	304		Do.
Do	304	8.50	Do.	Do	304		Do.
TEST 2.				TEST 4.			
Apr. 6	304	4.06	No ignition.	Mar. 25	a 680	3.94	No ignition.
Do	304	4.06	Do.	Do	a 680	3.97	Do.
Do	304	3.98	Do.	Do	a 680	3.89	Do.
Do	304	4.15	Do.	Do	a 680	4.01	Do.
Do	304	4.57	Do.	Do	a 680	3.94	Do.
Do	304	4.15	Do.				
Do	304	4.11	Do.	TEST 5.			
Do	304	4.19	Do.				
Do	304	4.19	Do.	Mar. 25	a 680	2.10	No ignition.
Do	304	4.06	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
Apr. 26	13.90	43	3,094
Do.	13.64	43	3,152

Average rate of detonation, 3,123 meters (10,240 feet per second).

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Millisecond.*
Apr. 26	19.0	24.00	9.25	0.462
June 11	19.0	24.00	10.25	.512
Do.	20.0	25.26	9.50	.475

Average height of flame, 24.42 inches.
Average duration of flame, 0.483 millisecond.

IMPACT TESTS.

Date, May 7, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
15	1	Explosion.	13	1	Explosion.
14	1	Do.	12	5	No explosion.

The maximum height at which no explosion occurs is established at 12 centimeters (4.72 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 205 grams.

Date (1909).	Distance separating cartridges	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
May 24	10	Exploded.	May 27	14	Did not explode.
May 27	12	Did not explode.	May 28	14	Exploded.
Do.	11	Do.	Do.	15	Do.
Do.	11	Exploded.	Do.	16	Did not explode.
Do.	12	Do.	Do.	16	Do.
Do.	13	Do.	Do.	16	Do.

The minimum distance at which no explosion occurs is established at 16 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 centimeter=1 kilogram per square centimeter.

Date (1909).	Charge	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
May 10	200	1.18	27.75	69.38	A	
Do	200	1.18	27.50	68.75	A	68.33
Do	200	1.18	26.75	66.88	A	
May 8	200	1.18	25.50	63.75	B	
Do	200	1.18	25.25	63.12	B	63.33
Do	200	1.18	25.25	63.12	B	
Do	200	1.18	24.00	60.00	C	
May 10	200	1.18	24.80	62.00	C	60.66
Do	200	1.18	24.00	60.00	C	

$P = 1.911A + 0.5B - 1.411C = 76.65$ kilograms per square centimeter.
$V = 15,000$ cubic centimeters. $S. = 1.12$. $W = 200$ grams.

$M = \dfrac{VPS}{W} = 6,439$ kilograms per square centimeter (91,578 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, April 23, 1909.

Grams.
Solid 74.2
Liquor (water) 13.8
Gaseous 104.4

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	*°C.*	*Calories.*
Apr. 19	84.13	0.809	765.5
Do	83.95	.818	772.6
Apr. 20	82.83	.835	779.5

Average large calories per kilogram of explosive, 772.5.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
Apr. 8	64.0	50.0	14.0
Do	64.0	49.7	14.3
Apr. 12	64.0	50.0	14.0

Average compression, 14.1 millimeters (0.56 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	*Cubic centimeters.*	*Cubic centimeters.*	*Cubic centimeters.*
Apr. 10	62	215	153	15
Do	62	208	146	15
Do	62	204	142	15

Average expansion of bore hole, 147 cubic centimeters (8.97 cubic inches).

COALITE NO. 1.

Explosive, Coalite No. 1.

Class, nitroglycerin.

Manufactured by Potts Powder Co.

Physical examination:

Diameter of cartridge, 1¼ inches.

Length of cartridge, 8 inches.

Average weight, 225 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 1.32.

Color of explosive, light ocher.

Consistency, granular.

Unit deflective charge as determined by the ballistic pendulum:

Date, March 1, 1909.

Unit swing used on this date, 3.01 inches.

Weight of charge, in grams, 290, 290, 290.

Swing, in inches, 3.00, 2.93, 2.91.

Average swing, in inches, 2.95.

2.95:3.01::290:(296).

Therefore the unit deflective charge of Coalite No. 1 is 296 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	*Per cent.*			*Grams.*	*Per cent.*	
Mar. 8	296	8.04	No ignition.	Mar. 10	296		No ignition.
Do	296	7.97	Do.	Do	296		Do.
Do	296	7.97	Do.	Do	296		Do.
Do	296	7.77	Do.	Do	296		Do.
Do	296	7.98	Do.	Do	296		Do.
Do	296	8.46	Do.	Do	296		Do.
Mar. 9	296	7.84	Do.	Mar. 11	296		Do.
Do	296	7.87	Do.	Do	296		Do.
Do	296	7.96	Do.	Do	296		Do.
Do	296	7.94	Do.	Do	296		Do.
TEST 2.				TEST 4.			
Mar. 9	296	3.91	No ignition.	Mar. 15	a 680	3.97	No ignition.
Do	296	3.87	Do.	Do	a 680	4.02	Do.
Do	296	4.09	Do.	Do	a 680	3.97	Do.
Do	296	3.95	Do.	Mar. 16	a 680	3.92	Do.
Do	296	4.20	Do.	Do	a 680	3.92	Do.
Do	296	4.12	Do.				
Do	296	4.14	Do.	TEST 5.			
Do	296	4.01	Do.				
Do	296	4.03	Do.	Mar. 16	a 680	2.08	No ignition.
Do	296	4.10	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
Apr. 5..	18.16	43	2,368
Apr. 6..	17.42	43	2,468

Average rate of detonation, 2,418 meters (7,930 feet) per second.

- FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters	*Inches.*	*Millimeters.*	*Millisecond.*
Apr. 9...	15.00	18.95	6.80	0.325
Do..	13.50	17.05	5.80	.290
Apr. 13..	13.80	17.43	4.80	.240

* Average height of flame, 17.81 inches.
Average duration of flame, 0.285 millisecond.

IMPACT TESTS.

Date, March 18, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
15	1	Explosion.	12	1	Explosion.
12	1	No explosion.	11	1	Do.
14	4	Do.	10	3	No explosion.
14	1	Explosion.	10	1	Explosion.
13	1	Do.	9	5	No explosion.
12	1	No explosion.			

The maximum height at which no explosion occurs is established at 9 centimeters (3.54 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 225 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
Apr. 2............	6	Exploded.	Apr. 3............	8	Did not explode.
Do............	8	Did not explode.	Do............	8	Do.
Do............	7	Exploded.			

The minimum distance at which no explosion occurs is established at 8 inches.

THEORETICAL MAXIMÚM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
Apr. 6	200	1. 42	26. 25	65. 62	A	
Do	200	1. 37	26. 50	66. 25	A	67. 08
Do	200	1. 42	27. 75	69. 38	A	
Apr. 3	200	1. 58	24. 50	61. 25	B	
Apr. 7	200	1. 38	25. 25	63. 12	B	61. 88
Do	200	1. 49	24. 50	61. 25	B	
Apr. 5	200	1. 42	24. 00	60. 00	C	
Do	200	1. 42	23. 25	58. 12	C	59. 58
Do	200	1. 42	24. 25	60. 62	C	

$P=1.911A+0.5B-1.411C=75.06$ kilograms per square centimeter.
$V=15,000$ cubic centimeters. $S=1.32$. $W=200$ grams.

$N=\dfrac{VPS}{W}=7,431$ kilograms per square centimeter (105,687 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, June 29, 1909.

Grams.
Solid 62.3
Liquid (water) 12.0
Gaseous 105.3

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Height of water.	Rise in temperature.	Development per kilogram.
	Kilograms.	*°C.*	*Calories.*
Apr. 5	83. 53	0. 764	717. 8
Do	83. 35	.749	702. 2
Apr. 6	83. 68	.778	732. 3

Average large calories per kilogram of the explosive, 717.4.

COMPRESSION OF SMALL LEAD BLOCKS.
Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
Mar. 26	64. 0	51. 5	12. 5
Do	64. 0	52. 0	12. 0
Do	64. 0	52. 0	12. 0

Average compression, 12.2 millimeters (0.48 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Tempera- ture of block.
	Before shot.	After shot.		
	Cubic centi- meters.	*Cubic centi- meters.*	*Cubic centi- meters.*	*°C.*
Mar. 10	62	221	159	17
Do	62	218	156	17
Do	62	218	156	17

Average expansion of bore hole, 157 cubic centimeters (9.58 cubic inches).

COALITE NO. 2 D.

Explosive: Coalite No. 2 D.

Class: Nitroglycerin.

Manufactured by Potts Powder Co.

Physical examination:

> Diameter of cartridge, 1¼ inches.
>
> Length of cartridge, 8 inches.
>
> Average weight, 220 grams.
>
> Cartridge had not been redipped.
>
> Apparent specific gravity of cartridge by sand, 1.27.
>
> Color of explosive, buff.
>
> Consistency, granular, moderately cohesive.

Unit deflective charge as determined by the ballistic pendulum.

> Date, March 1, 1909.
>
> Unit swing used on this date, 3.01 inches.
>
> Weight of charge, in grams, 315, 315, 315.
>
> Swing, in inches, 3.08, 3.04, 3.05.
>
> Average swing, in inches, 3.06.

3.06 : 3.01 :: 315 : (310).

Therefore the unit deflective charge of Coalite No. 2 D is 310 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	*Per cent.*			*Grams.*	*Per cent.*	
Mar. 9	310	7.91	No ignition.	Mar. 11	310		No ignition.
Do	310	7.79	Do.	Do	310		Do.
Do	310	7.84	Do.	Do	310		Do.
Do	310	8.05	Do.	Do	310		Do.
Do	310	7.85	Do.	Do	310		Do.
Do	310	7.79	Do.	Do	310		Do.
Do	310	8.08	Do.	Do	310		Do.
Do	310	8.08	Do.	Do	310		Do.
Do	310	7.84	Do.	Do	310		Do.
Do	310	8.04	Do.	Do	310		Do.
TEST 2.				TEST 4.			
Mar. 9	310	3.97	No ignition.	Mar. 13	a 680	4.03	No ignition.
Do	310	4.15	Do.	Do	a 680	4.03	Do.
Do	310	4.13	Do.	Do	a 680	4.12	Do.
Do	310	4.01	Do.	Mar. 14	a 680	3.98	Do.
Do	310	4.06	Do.	Mar. 15	a 680	3.94	Do.
Do	310	4.06	Do.				
Mar. 10	310	4.06	Do.	TEST 5.			
Do	310	4.03	Do.				
Do	310	4.15	Do.	Mar. 16	a 680	2.00	No ignition.
Do	310	4.03	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches
Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
Apr. 6..	16.83	43	2,555
Apr. 7..	16.62	43	2,587

Average rate of detonation, 2,571 meters (8,430 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
Apr. 9..	16.50	20.84	7.00	0.350
Apr. 13......................................	16.00	20.21	6.50	.325
Do..	16.00	20.21	7.00	.350

Average height of flame, 20.42 inches.
Average duration of flame, 0.342 milliseconds.

IMPACT TESTS.

Date, March 8, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
20	1	Explosion.	13	1	Explosion.
15	1	No explosion.	12	1	No explosion.
18	1	Explosion.	12	1	Explosion.
17	1	Do.	11	1	Do.
16	1	Do.	10	1	No explosion.
15	1	Do.	10	1	Explosion.
14	2	No explosion.	9	5	No explosion.
14	1	Explosion.			

The maximum height at which no explosion occurs is established at 9 centimeters (3.54 inches).

EXPLOSION BY INFLUENCE TEST

Weight of each cartridge, 220 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
Apr. 10..........	6	Did not explode.	Apr. 12..........	3	Exploded.
Apr. 12..........	4	Do.	Do..........	4	Did not explode.
Do..........	2	Exploded.	Do..........	4	Do.

The minimum distance at which no explosion occurs is established at 4 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
Apr. 10	200	1.24	25.75	64.38	A	
Apr. 13	200	1.28	26.50	66.25	A	65.84
Do	200	1.28	26.75	66.88	A	
Apr. 8	200	1.28	24.50	61.25	B	
Do	200	1.28	24.50	61.25	B	60.83
Do	200	1.28	24.00	60.00	B	
Apr. 9	200	1.28	24.00	60.00	C	
Do	200	1.28	23.25	58.12	C	58.54
Apr. 10	200	1.24	23.00	57.50	C	

P=1.911A+0.5B−1.411C=73.64 kilograms per square centimeter.

V=15,000 cubic centimeters.   S=1.27.   W=200 grams.

$M=\dfrac{VPS}{W}=7{,}014$ kilograms per square centimeter (99,756 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, April 7, 1909.   Grams.

Solid 82. 3

Liquid (water) 11. 4

Gaseous 85. 5

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Development per kilogram.
	Kilograms.	*° C.*	*Calories.*
Apr. 9	83.46	0.844	793.3
Do	83.28	.843	790.8
Apr. 10	84.48	.826	784.6

Average large calories per kilogram of the explosive, 789.6.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height. Before explosion.	Height. After explosion.	Compression.
	Millimeters.	*Millimeters.*	*Millimeters.*
Mar. 26	64.0	52.0	12.0
Do	64.0	52.0	12.0
Do	64.0	52.7	11.3

Average compression, 11.8 millimeters (0.46 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Tempera-ture of block.
	Before shot.	After shot.		
	Cubic centi-meters.	Cubic centi-meters.	Cubic centi-meters.	°C.
Mar. 10	62	212	150	17
Do	62	207	145	17
Do	62	206	144	17

Average expansion of bore hole, 146 cubic centimeters (8.91 cubic inches).

COLLIER POWDER NO. 2.

Explosive, Collier Powder No. 2.

Class, nitroglycerin.

Manufactured by Keystone National Powder Co.

Physical examination:

Diameter of cartridge, 1¼ inches.

Length of cartridge, 8 inches.

Average weight, 148 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 0.84.

Color of explosive, drab.

Consistency, dry, fibrous.

Unit deflective charge as determined by the ballistic pendulum:

Date, April 5, 1909.

Unit swing used on this date, 2.80 inches.

Weight of charge, in grams, 280, 280, 280.

Swing, in inches, 2.65, 2.55, 2.65.

Average swing, in inches, 2.617.

$$2.617 : 2.80 :: 280 : (300).$$

Therefore the deflective charge of Collier Powder No. 2 is 300 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	Per cent.			Grams.	Per cent.	
Apr. 9	300	7.90	No ignition.	Apr. 9	300		No ignition.
Do	300	7.88	Do.	Do	300		Do.
Do	300	7.96	Do.	Do	300		Do.
Do	300	8.11	Do.	Do	300		Do.
Do	300	7.98	Do.	Do	300		Do.
Do	300	7.88	Do.	Do	300		Do.
Do	300	7.83	Do.	Do	300		Do.
Do	300	8.06	Do.	Do	300		Do.
Do	300	7.88	Do.	Do	300		Do.
Do	300	7.83	Do.	Do	300		Do.
TEST 2.				TEST 4.			
Apr. 8	300	3.94	No ignition.	Apr. 10	a 680	4.28	No ignition.
Do	300	3.94	Do.	Do	a 680	4.04	Do.
Do	300	4.04	Do.	Apr. 11	a 680	3.79	Do.
Do	300	4.04	Do.	Do	a 680	3.86	Do.
Do	300	4.03	Do.	Do	a 680	3.94	Do.
Do	300	4.11	Do.				
Do	300	4.11	Do.	TEST 5.			
Do	300	4.03	Do.				
Do	300	4.11	Do.	Apr. 22	a 680	2.10	No ignition.
Do	300	4.03	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 7.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
May 15	16.97	43	2,694
June 18	15.85	43	2,713

Average rate of detonation, 2,704 meters (8,870 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
May 22	15.75	19.89	6.50	0.325
Do	16.00	20.21	7.50	.375
Do	15.25	19.26	7.25	.362

Average height of flame, 19.79 inches.
Average duration of flame, 0.354 millisecond.

IMPACT TEST.

Date, June 3, 1909.

Distance of fall.	Number of falls.	Result.	Distance of falls.	Number of falls.	Result.
Centimeters. 15	1	Explosion.	*Centimeters.* 14	5	No explosion.

The maximum height at which no explosion occurs is established at 14 centimeters (5.51 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 149 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
June 7	6	Did not explode.	June 7	3	Exploded.
Do	4	Do.	June 8	4	Did not explode.
Do	2	Exlpoded.	Do	4	Do.
Do	3	Did not explode.			

The minimum distance at which no explosion occurs is established at 4 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
May 28	200	0.93	26.50	66.25	A	
Do	200	.91	28.00	70.00	A	67.92
May 29	200	.93	27.00	67.50	A	
May 26	200	.86	24.50	61.25	B	
Do	200	.86	24.75	61.88	B	61.46
May 27	200	.86	24.50	61.25	B	
Do	200	.86	23.50	58.75	C	
June 1	200	.93	22.75	56.88	C	58.12
Do	200	.93	23.50	58.75	C	

P=1.911 A+0.5 B−1.411 C=78.52 kilograms per square centimeter.
V=15,000 cubic centimeters.   S=0.84.   W=200 grams.

$M=\dfrac{VPS}{W}$=4,947 kilograms per square centimeter (70,358 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 14, 1909.

Grams.
Solid.. 60.3
Liquid (water)... 14.7
Gaseous.. 114.6

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	*°C.*	*Calories.*
June 9	82.27	0.765	709.1
June 10	82.27	.740	685.7
Do	82.27	.751	696.0

Average large calories per kilogram of explosive, 696.9.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height before explosion.	Height after explosion.	Compression.
	Millimeters.	*Millimeters.*	*Millimeters.*
Apr. 15	64.0	51.5	12.5
Apr. 21	64.0	51.3	12.7
Do	63.8	51.7	12.1

Average compression, 12.4 millimeters (0.48 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole before shot.	Volume of bore hole after shot.	Expansion of bore hole.	Temperature of block.
	Cubic centimeters.	Cubic centimeters.	Cubic centimeters.	°C.
Apr. 10	62	222	160	15
Do	62	212	150	15
Do	62	205	143	15

Average expansion of bore hole, 151 cubic centimeters (9.21 cubic inches).

COLLIER POWDER NO. 4.

Explosive: Collier Powder No. 4.

Class, nitroglycerin.

Manufactured by Keystone National Powder Co.

Physical examination:

Diameter of cartridge, 1¼ inches.

Length of cartridge, 8 inches.

Average weight, 150 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 0.88.

Color of explosive, light buff.

Consistency, dry, fibrous.

Unit deflective charge as determined by the ballistic pendulum:

Date, April 7, 1909.

Unit swing used on this date, 2.80 inches.

Weight of charge, in grams, 280, 280, 280.

Swing, in inches, 2.94, 2.78, 2.80.

Average swing, in inches, 2.84.

2.84 : 2.80 : : 280 : : (276).

Therefore the unit deflective charge of Collier Powder No. 4 is 276 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	Per cent.			Grams.	Per cent.	
Apr. 8	276	8.24	No ignition.	Apr. 9	276		No ignition.
Do	276	8.14	Do.	Do	276		Do.
Do	276	8.22	Do.	Do	276		Do.
Do	276	8.11	Do.	Do	276		Do.
Do	276	8.09	Do.	Do	276		Do.
Apr. 9	276	8.06	Do.	Do	276		Do.
Do	276	8.06	Do.	Do	276		Do.
Do	276	7.83	Do.	Apr. 10	276		Do.
Do	276	7.90	Do.	Do	276		Do.
Do	276	7.81	Do.	Do	276		Do.
TEST 2.				TEST 4.			
Apr. 8	276	4.03	No ignition.	Apr. 10	a 680	4.03	No ignition.
Do	276	4.28	Do.	Apr. 11	a 680	4.03	Do.
Do	276	4.19	Do.	Do	a 680	4.03	Do.
Do	276	4.19	Do.	Apr. 21	a 680	4.10	Do.
Do	276	4.11	Do.	Do	a 680	4.19	Do.
Do	276	4.03	Do.				
Do	276	4.19	Do.				
Do	276	4.19	Do.	TEST 5.			
Do	276	4.03	Do.				
Do	276	4.11	Do.	Apr. 21	a 680	2.09	No ignition.

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 7.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
June 18	12.39	43	3,471
June 24	13.15	43	3,270

Average rate of detonation, 3,370 meters (11,050 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
May 28	20.50	25.89	10.25	0.512
Do	20.50	25.89	9.75	.488
Do	21.25	26.84	9.25	.462

Average height of flame, 26.21 inches.
Average duration of flame, 0.487 millisecond.

IMPACT TESTS.

Date, June 3, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
15	1	No explosion.	18	1	Explosion.
20	1	Do.	17	1	Do.
25	1	Explosion.	16	1	Do.
24	1	Do.	15	1	No explosion.
23	1	Do.	15	1	Explosion.
22	1	Do.	14	1	Do.
21	1	Do.	13	1	No explosion.
20	1	Do.	13	1	Explosion.
19	1	Do.	12	5	No explosion.

The maximum height at which no explosion occurs is established at 12 centimeters (4.72 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 150 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
June 8	4	Exploded.	June 8	5	Exploded.
Do	6	Did not explode.	June 9	6	Did not explode.
Do	5	Do.	Do	6	Do.

The minimum distance at which no explosion occurs is established at 6 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
June 2	200	0.90	27.50	68.75	A	
Do	200	.90	28.00	70.00	A	69.58
Do	200	.90	28.00	70.00	A	
June 3	200	.90	26.00	65.00	B	
Do	200	.90	24.75	61.88	B	63.54
Do	200	.90	25.50	63.75	B	
Do	200	.90	24.00	60.00	C	
June 10	200	.90	24.00	60.00	C	61.25
Do	200	.90	25.50	63.75	C	

$P=1.911A+0.5B-1.411C=78.31$ kilograms per square centimeter.

$V=15,000$ cubic centimeters. $S=0.88$. $W=200$ grams.

$M=\dfrac{VPS}{W}=5,168$ kilograms per square centimeter (73,501 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 17, 1909.

Grams.
Solid 65.3
Liquid (water) 8.2
Gaseous 110.6

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Development per kilogram.
	Kilograms.	*° C.*	*Calories.*
June 10	83.27	0.815	764.2
June 11	83.27	.826	774.6
Do	83.27	.797	747.1

Average large calories per kilogram of explosive, 762.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
Apr. 15	64.0	50.0	14.0
Do	64.0	50.3	13.7
Apr. 21	63.8	49.5	14.3

Average compression, 14.0 millimeters (0.55 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.	
	Before shot.	After shot.			
	Cubic centimeters.	*Cubic centimeters.*	*Cubic centimeters.*	*°C.*	
Apr. 10	62	240	178	15	
Do	62	244	182	15	
Do	62	260	198	15	

Average expansion of bore hole, 186 cubic centimeters (11.35 cubic inches).

COLLIER POWDER NO. 5.

Explosive, Collier Powder No. 5.

Class, Ammonium nitrate, containing nitroglycerin.

Manufactured by Keystone National Powder Co.

Physical examination:

Diameter of cartridge, 1¼ inches.

Length of cartridge, 8 inches.

Average weight, 158.5 grams.

Cartridge had not been redipped.

Apparent specific gravity of cartridge by sand, 0.97.

Color of explosive, fawn.

Consistency, granular, cohesive.

Unit deflective charge as determined by the ballistic pendulum:

Date, April 5, 1909.

Unit swing used on this date, 2.80 inches.

Weight of charge in grams, 235, 235, 235.

Swing, in inches, 2.910, 2.725, 2.600.

Average swing in inches, 2.745.

2.745:2.80::235:(240).

Therefore the unit deflective charge of Collier Powder No. 5 is 240 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	*Per cent.*			*Grams.*	*Per cent.*	
Apr. 9	240	8.09	No ignition.	Apr. 9	240		No ignition.
Do	240	8.09	Do.	Apr. 10	240		Do.
Do	240	7.97	Do.	Do	240		Do.
Do	240	7.97	Do.	Do	240		Do.
Do	240	7.98	Do.	Do	240		Do.
Do	240	8.01	Do,	Do	240		Do.
Do	240	7.94	Do.	Do	240		Do.
Do	240	8.26	Do.	Do	240		Do.
Do	240	7.97	Do.	Do	240		Do.
Do	240	8.11	Do.	Do	240		Do.
TEST 2.				TEST 4.			
Apr. 8	240	4.19	No ignition.	Apr. 10	a 680	4.11	No ignition.
Do	240	4.21	Do.	Apr. 11	a 680	3.96	Do.
Do	240	4.19	Do.	Apr. 22	a 680	3.96	Do.
Do	240	4.36	Do.	Do	a 680	4.20	Do.
Do	240	4.22	Do.	Do	a 680	4.65	Do.
Do	240	3.96	Do.				
Do	240	4.11	Do.	TEST 5.			
Do	240	4.11	Do.				
Do	240	4.03	Do.	Apr. 22	a 680	2.02	No ignition.
Do	240	4.19	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 7.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
June 24	17.20	43	2,500
June 25	16.88	43	2,547

Average rate of detonation 2,524 meters (8,280 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
May 13	15.25	19.26	7.50	0.375
Do	15.50	19.58	7.00	.350
May 22	16.00	20.21	6.00	.300

Average height of flame, 19.68 inches.
Average duration of flame, 0.342 milliseconds.

IMPACT TESTS.

Date, June 25, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
20	1	No explosion.	30	1	Explosion.
25	1	Do.	25	1	No explosion.
40	1	Explosion.	26	1	Explosion.
35	1	Do.	25	1	No explosion.
30	1	No explosion.	25	1	Explosion
34	1	Do.	24	1	Do.
34	1	Explosion.	23	3	No explosion.
33	1	Do.	23	1	Explosion.
32	1	Do.	22	5	No explosion.
31	1	Do.			

The maximum height at which no explosion occurs is established at 22 centimeters (8.66 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 159 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
June 10	4	Did not explode.	June 10	2	Did not explode.
Do	2	Do.	Do	2	Do.
Do	1	Exploded.			

The minimum distance at which no explosion occurs is established at 2 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
June 3	200	1.04	36.50	91.25	A	
Do	200	1.04	37.50	93.75	A	93.12
June 4	200	1.04	37.75	94.38	A	
June 11	200	1.04	32.00	80.00	B	
June 12	200	1.04	27.80	69.50	B	
Do	200	1.04	26.50	66.25	B	
June 14	200	1.02	34.20	85.50	B	73.12
Do	200	1.02	28.50	71.25	B	
Do	200	1.02	28.50	71.25	B	
Do	200	1.04	27.25	68.12	B	
June 12	200	1.04	27.00	67.50	C	
Do	200	1.04	25.50	63.75	C	67.03
Do	200	1.04	26.00	65.00	C	
June 14	200	1.04	28.75	71.88	C	

$P=1.911A+0.5B-1.411C=119.93$ kilograms per square centimeter.
$V=15,000$ cubic centimeters. $S=0.97$. $W=200$ grams.

$M = \dfrac{VPS}{W} = 8,725$ kilograms per square centimeter (124,090 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 20, 1909.

Grams.
Solid 17.8
Liquid (water) 71.5
Gaseous 96.2

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	*°C.*	*Calories.*
June 11	83.15	0.949	890.1
June 25	82.13	.898	832.6

Average large calories per kilogram of explosive, 861.4.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
Apr. 15	64.0	52.0	12.0
Do	64.0	51.3	12.7
Do	64.0	51.3	12.7

Average compression, 12.5 millimeters (0.49 cubic inches).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Tempera-ture of block.
	Before shot.	After shot.		
	Cubic centimeters.	*Cubic centimeters.*	*Cubic centimeters.*	°C.
Apr. 10	62	262	200	15
Do	62	270	208	15
Apr. 12	62	278	216	15

Average expansion of bore hole, 208 cubic centimeters (12.69 cubic inches).

MASURITE M. L. F.

Explosive, Masurite M. L. F.

Class, ammonium nitrate.

Manufactured by Masurite Explosives Co.

Physical examination:

Packed loose in 5-pound waterproof canisters.

Color of explosive, iron gray.

Apparent specific gravity of prepared cartridge by sand, 0.97.

Consistency, granular dry powder.

Unit deflective charge as determined by the ballistic pendulum:

Date, April 30, 1909.

Unit swing used on this date: 2.77 inches.

Weight of charge, in grams: 266, 266, 266.

Swing, in inches: 2.68, 2.56, 2.67.

Average swing, in inches: 2.64.

$$2.64 : 2.77 : : 266 : (279).$$

Therefore the unit deflective charge of Masurite M. L. F. is 279 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				**TEST 3.**			
	Grams.	*Per cent.*			*Grams.*	*Per cent.*	
May 3	279	7.96	No ignition.	May 5	279		No ignition.
Do	279	8.07	Do.	Do	279		Do.
Do	279	8.16	Do.	Do	279		Do.
Do	279	8.66	Do.	Do	279		Do.
Do	279	8.10	Do.	Do	279		Do.
Do	279	8.25	Do.	Do	279		Do.
Do	279	8.25	Do.	Do	279		Do.
May 4	279	8.22	Do.	Do	279		Do.
Do	279	8.14	Do.	Do	279		Do.
Do	279	8.20	Do.	Do	279		Do.
TEST 2.				**TEST 4.**			
May 4	279	4.14	No ignition.	May 1	a 680	4.05	No ignition.
Do	279	4.22	Do.	Do	a 680	3.98	Do.
Do	279	4.24	Do.	Do	a 680	4.20	Do.
Do	279	4.22	Do.	Do	a 680	3.94	Do.
Do	279	4.24	Do.	Do	a 680	4.14	Do.
Do	279	4.17	Do.				
Do	279	4.06	Do.	**TEST 5.**			
Do	279	4.12	Do.				
Do	279	4.15	Do.	May 1	a 680	2.10	No ignition.
Do	279	4.26	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1⅜ inches.
Electric detonator, No. 7.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
Aug. 14	13.00	45	3,462
Aug. 17	12.60	43	3,413

Average rate of detonation, 3,488 meters (11,280 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
May 27	20.50	25.89	10.00	0.500
Do	20.00	25.26	9.00	.450
Do	20.50	25.89	10.00	.500

Average height of flame, 25.68 inches.
Average duration of flame, 0.483 milliseconds.

IMPACT TESTS.

Date, May 5, 1909.

Distance of fall.	Number of falls.	Result.	Distance of falls.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
60	1	Explosion.	15	1	No explosion.
50	1	Do.	19	3	Explosion.
40	1	Do.	18	2	No explosion.
30	1	Do.	18	1	Explosion.
20	1	Do.	17	5	No explosion.

The maximum height at which no explosion occurs is established at 17 centimeters (6.69 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 159 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
Aug. 19	2	Did not explode.	Aug. 19	2	Did not explode.
Do	1	Exploded.	Do.	2	Do.

The minimum distance at which no explosion occurs is established at 2 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
June 21	200	1.05	36.75	91.88	A	⎫
Do	200	1.05	35.12	87.80	A	⎬ 89.45
Do	200	1.05	35.25	88.12	A	⎪
June 22	200	1.05	36.00	90.00	A	⎭
June 21	200	1.05	35.50	88.75	B	⎫
Do	200	1.05	32.38	80.95	B	⎬ 82.82
June 22	200	1.05	31.50	78.75	B	⎭
Do	200	1.05	31.75	79.38	C	⎫
Do	200	1.05	32.25	80.62	C	⎬ 79.38
June 23	200	1.05	31.25	78.12	C	⎭

P=1.911A+0.5 B−1.411 C=100.34 kilograms per square centimeter.

V=15.000 cubic centimeters.   S=0.97.   W=200 grams.

$M=\dfrac{VPS}{W}$=7,300 kilograms per square centimeter (103,824 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 21, 1909.

	Grams.
Solid	27.5
Liquid (water)	75.5
Gaseous	89.8

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	*°C.*	*Calories.*
June 25	82.13	1.055	979.7
Do	82.13	1.068	991.9
Do	82.13	1.084	1006.9

Average large calories per kilogram of explosive, 992.8.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
May 12	64.0	49.8	14.2
Do	64.0	49.8	14.2
Do	64.0	50.0	14.0

Average compression, 14.1 millimeters (0.56 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Tempera-ture of block.
	Before shot.	After shot.		
	Cubic centi-meters.	*Cubic centi-meters.*	*Cubic centi-meters.*	*°C.*
June 29	62	290	223	29
Do	62	280	218	20

Average expansion of bore hole, 223 cubic centimeters (13.60 cubic inches).

METEOR AXXO.

Explosive, Meteor AXXO.

Class, hydrated, containing nitroglycerin.

Manufactured by E. I. Du Pont de Nemours Powder Co.

Physical examination:

 Diameter of cartridge, 1½ inches.

 Length of cartridge, 8 inches.

 Average weight, 356 grams.

 Cartridge had been redipped in paraffin.

 Apparent specific gravity of cartridge by sand, 1.54.

 Color of explosive, dove-colored mass with glistening black particles.

 Consistency, cohesive.

Unit deflective charge as determined by the ballistic pendulum:

 Date, February 13, 1909.

 Unit swing used on this date, 3.01 inches.

 Weight of charge, in grams, 440, 440, 440.

 Swing, in inches, 2.99, 3.00, 3.07.

 Average swing, in inches, 3.05.

 3.05: 3.01: 440: (434).

Therefore the unit deflective charge of Meteor AXXO is 434 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				TEST 3.			
	Grams.	*Per cent.*			*Grams.*	*Per cent.*	
Feb. 16	434	8.02	No ignition.	Feb. 19	434		No ignition.
Do	434	7.88	Do.	Do	434		Do.
Do	434	7.90	Do.	Do	434		Do.
Do	434	7.85	Do.	Do	434		Do.
Do	434	7.77	Do.	Do	434		Do.
Do	434	7.95	Do.	Do	434		Do.
Do	434	7.89	Do.	Do	434		Do.
Do	434	7.80	Do.	Do	434		Do.
Do	434	8.02	Do.	Do	434		Do.
Do	434	7.88	Do.	Do	434		Do.
TEST 2.				TEST 4.			
Feb. 17	434	4.04	No ignition.	Feb. 21	a 680	3.83	No ignition.
Do	434	3.97	Do.	Do	a 680	3.79	Do.
Do	434	3.93	Do.	Do	a 680	3.74	Do.
Do	434	4.02	Do.	Feb. 23	a 680	3.85	Do.
Do	434	3.74	Do.	Do	a 680	4.03	Do.
Do	434	3.95	Do.				
Do	434	3.96	Do.	TEST 5.			
Do	434	4.01	Do.				
Do	434	4.04	Do.	Feb. 24	a 680	2.04	No ignition.
Do	434	4.03	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 7.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
Aug. 13..	17.03	43	2,525
Do...	16.53	43	2,601

Average rate of detonation 2,563 meters (8,410 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration. distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
Mar. 12..	14.00	17.68	6.62	0.331
Do..	13.75	17.87	6.75	.338
Do..	14.38	18.16	6.62	.331

Average height of flame, 17.74 inches.
Average duration of flame, 0.333 milliseconds.

IMPACT TESTS.

Date, February 19, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
15	1	Explosion.	10	2	No explosion.
14	1	Do.	10	1	Explosion.
13	1	Do.	9	2	No explosion.
12	1	Do.	9	1	Explosion.
11	1	Do.	8	5	No explosion

The maximum height at which no explosion occurs is established at 8 centimeters
(3.15 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 249 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
Mar. 23.........	6	Did not explode.	Mar. 24.........	3	Exploded.
Mar. 24.........	5	Do.	Mar. 26.........	4	Did not explode.
Do.........	4	Do.	Do.........	4	Do.

The minimum distance at which no explosion occurs is established at 4 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeters=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
Feb. 15	100	1.47	13.50	24.10	A	
Do	100	1.47	13.20	23.57	A	23.63
Feb. 17	100	1.47	13.00	23.21	A	
Mar. 26	100	1.57	11.00	19.64	B	
Do	100	1.57	11.50	20.54	B	20.09
Do	100	1.57	11.25	20.09	B	
Mar. 27	100	1.57	11.25	20.09	C	
Do	100	1.57	10.45	18.66	C	19.17
Do	100	1.57	10.50	18.75	C	

P=1.911A+0.5B−1.411C=28.56 kilograms per square centimeter.

V=15,000 cubic centimeters.　　S=1.54.　　W=100 grams.

$$M=\frac{VPS}{W}=6,597 \text{ kilograms per square centimeter (93,825 pounds per square inch).}$$

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, May 24, 1909.

Grams.

Solid.. 56.0

Liquid (water).. 33.0

Gaseous... 86.1

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	*° C.*	*Calories.*
Mar. 26	81.25	0.647	591.8
Do	81.49	.674	618.5
Mar. 27	83.48	.663	621.4

Average large calories per kilogram of explosive, 610.6.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
Feb. 16	64.0	54.8	9.2
Do	64.0	54.5	9.5
Do	64.0	55.0	9.0

Average compression, 9.2 millimeters (0.36 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	*Cubic centimeters.*	*Cubic centimeters.*	*°C.*
Oct. 16	62	190	128	15
Do	62	195	133	15
Do	62	194	132	15

Average expansion of bore hole, 131 cubic centimeters (7.99 cubic inches).

MONOBEL NO. 1.

Explosive, Monobel No. 1.

Class, ammonium nitrate, containing nitroglycerin.

Manufactured by E. I. Du Pont de Nemours Powder Co.

Physical examination:

Diameter of cartridge, 1½ inches.

Length of cartridge, 8 inches.

Average weight, 220 grams.

Cartridge had been redipped in paraffin.

Apparent specific gravity of cartridge by sand, 0.97.

Color of explosive, ocher.

Consistency, rather dry, fibrous powder.

Unit deflective charge as determined by the ballistic pendulum:

Date, February 2, 1909.

Unit swing used on this date, 3.01 inches.

Weight of charge, in grams, 225, 225, 225.

Swing, in inches, 3.22, 3.11, 3.09.

Average swing, in inches, 3.14.

$$3.14 : 3.01 : : 225 : (216).$$

Therefore the unit deflective charge of Monobel No. 1 is 216 grams.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.	Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 1.				**TEST 3.**			
	Grams.	*Per cent.*			*Grams.*	*Per cent.*	
Feb. 8	216	8.43	No ignition.	Feb. 4	216	....	No ignition.
Do	216	7.96	Do.	Do	216	....	Do.
Do	216	7.84	Do.	Do	216	....	Do.
Do	216	8.33	Do.	Do	216	....	Do.
Do	216	8.04	Do.	Do	216	....	Do.
Do	216	7.91	Do.	Do	216	....	Do.
Do	216	7.89	Do.	Do	216	....	Do.
Do	216	8.01	Do.	Do	216	....	Do.
Do	216	8.10	Do.	Feb. 5	216	....	Do.
Feb. 19	216	8.24	Do.	Do	216	....	Do.
TEST 2.				**TEST 4.**			
Feb. 4	216	4.15	No ignition.	Mar. 2	a 680	3.99	No ignition.
Do	216	4.13	Do.	Do	a 680	4.05	Do.
Do	216	3.85	Do.	Do	a 680	4.05	Do.
Do	216	3.98	Do.	Mar. 5	a 680	4.02	Do.
Do	216	4.00	Do.	Do	a 680	4.02	Do.
Do	216	4.04	Do.				
Do	216	3.88	Do.	**TEST 5.**			
Do	216	4.09	Do.				
Do	216	4.02	Do.	Feb. 12	a 680	2.01	No ignition.
Do	216	3.91	Do.				

a 680 grams or more were used.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
Mar. 10..	12.06	43	3,560
Mar. 11..	12.02	43	3,577

Average rate of detonation 3,568 meters (11,700 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
Mar. 11..	17.12	21.63	5.25	0.262
Do..	15.75	19.89	5.00	.250
Do..	17.62	22.26	5.25	.262

Average height of flame, 21.26 inches.
Average duration of flame, 0.258 milliseconds.

IMPACT TESTS.

Date, February 2, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
20	1	No explosion.	27	1	Explosion.
30	1	Explosion.	26	1	Do.
25	1	No explosion.	25	3	No explosion.
27	1	Do.	25	1	Explosion.
28	1	Explosion.	24	5	No explosion.

The maximum height at which no explosion occurs is established at 24 centimeters (9.45 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 175 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
Mar. 13............	8	Did not explode.	Mar. 15.........	2	Exploded.
Do............	6	Do.	Do.........	3	Did not explode.
Do............	4	Do.	Do.........	3	Explosion.
Do............	2	Do.	Do.........	4	Did not explode.
Do............	1	Exploded.	Do.........	4	Do.

The minimum distance at which no explosion occurs is established at 4 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 centimeters=1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
Mar. 13	100	0. 93	20. 63	51. 56	A	
Do	100	.93	19. 50	48. 75	A	50. 52
Do	100	.93	20. 50	51. 25	A	
Mar. 11	100	.93	18. 75	46. 88	B	
Do	100	.93	18. 75	46. 88	B	46. 67
Do	100	.93	18. 50	46. 25	B	
Mar. 12	100	.93	17. 50	43. 75	C	
Mar. 13	100	.93	17. 62	44. 05	C	43. 85
Do	100	.93	17. 50	43. 75	C	

P=1.911A+0.5B−1.411C=58.01 kilograms per square centimeter.

V=15,000 cubic centimeters.   S=0.97.   W=100 grams.

$M=\dfrac{VPS}{W}$=8,440 kilograms per square centimeter (120,037 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, June 28, 1909.

Grams.

Solid 2. 9

Liquid (water) 80. 5

Gaseous 110. 1

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 75 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	*° C.*	*Calories.*
Mar. 9	82. 45	0. 920	1, 141. 6
Mar. 10	82. 05	.936	1, 156. 7
Do	81. 85	.903	1, 113. 1

Average large calories per kilogram of explosive, 1,137.1.

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Date (1909).	Height.		Compression.
	Before explosion.	After explosion.	
	Millimeters.	*Millimeters.*	*Millimeters.*
Feb. 2	64. 0	54. 8	9. 2
Do	64. 0	54. 0	10. 0
Do	64. 0	54. 8	9. 2

Average compression, 9.5 millimeters (0.37 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCK.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Tempera- ture of block.
	Before shot.	After shot.		
	Cubic centi- meters.	*Cubic centi- meters.*	*Cubic centi- meters.*	*°C.*
Oct. 16	62	375	313	15
Do	62	364	302	15
Do	62	370	308	15

Average expansion of bore hole, 308 cubic centimeters (18.79 cubic inches).

CHAPTER VI.

RESULTS OF TESTS WITH DYNAMITE.

By CLARENCE HALL and S. P. HOWELL.

PITTSBURGH TESTING STATION STANDARD DYNAMITE.

Explosive, Pittsburgh Testing Station standard dynamite.
Class, nitroglycerin.
Physical examination:
    Diameter of cartridge, 1¼ inches.
    Length of cartridge, 8 inches.
    Average weight, 229 grams.
    Cartridge had been redipped in paraffin.
    Apparent specific gravity of cartridge by sand, 1.22.
    Color of explosive, cafe-au-lait.
    Consistency, fibrous and cohesive.
Determination of unit swing by ballistic pendulum:
    Charge, 227 grams—
        Date, November 26, 1909—
            Swing, in inches, 2.92, 2.97, 2.85.
            Average swing, in inches, 2.91.
        Date, January 25, 1909—
            Swing, in inches, 3.095, 2.940, 2.995.
            Average swing, in inches, 3.01.
        Date, April 5, 1909—
            Swing, in inches, 2.865, 2.730, 2.805.
            Average swing in inches, 2.80.
        Date, April 30, 1909—
            Swing, in inches, 2.70, 2.82, 2.80.
            Average swing, in inches, 2.77.
        Date, May 10, 1909—
            Swing, in inches, 2.92, 2.88, 2.78.
            Average swing, in inches, 2.86.

GAS AND DUST GALLERY No. 1.

Date (1909).	Weight of charge.	Methane and ethane.	Result.
TEST 4.	*Grams.*	*Per cent.*	
Oct. 27	100	4.08	Ignition.
Do	50	4.08	Do.
Do	25	4.08	Do.

Limit charge established at 0 gram.

During the period covered by this report many tests were run with 40 per cent nitroglycerin dynamite of the grade herein reported and other grades, and in every case ignition resulted whether the explosive was fired into gas and air, dust and air, or gas, dust, and air.

RATE OF DETONATION.

Diameter of cartridge, 1¼ inches.
Electric detonator, No. 6.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of detonation per second.
	Millimeters.	*Meters.*	*Meters.*
Mar. 6	9.357	43.5	4,649
Do	9.200	43.5	4,728

Average rate of detonation, 4,688 meters (15,380 feet) per second.

FLAME TEST.

Peripheral speed of film, 20 meters per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
Oct. 28	19.50	24.63	7.00	0.350
Do	17.50	22.11	6.50	.325
Do	21.50	27.16	8.00	.400

Average height of flame, 24.63 inches.
Average duration of flame, 0.358 milliseconds.

IMPACT TEST.
Date, January 22, 1909.

Distance of fall.	Number of falls.	Result.	Distance of fall.	Number of falls.	Result.
Centimeters.			*Centimeters.*		
11	2	No explosion.	10	5	No explosion.
11	1	Explosion.			

The maximum height at which no explosion occurs is established at 10 centimeters
(3.94 inches).

EXPLOSION BY INFLUENCE TEST.

Weight of each cartridge, 196 grams.

Date (1909).	Distance separating cartridges.	Result, upper cartridge.	Date (1909).	Distance separating cartridges.	Result, upper cartridge.
	Inches.			*Inches.*	
Nov. 15	13	Exploded.	Nov. 16	16	Did not explode.
Do	14	Did not explode.	Do	16	Exploded.
Do	14	Exploded.	Do	17	Did not explode.
Do	14	Do.	Do	17	Do.
Nov. 16	15	Do.	Do	17	Do.

The minimum distance at which no explosion occurs is established at 17 inches.

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME, AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeter=1 kilogram per square centimeter.

Date (1908).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
Dec. 16	100	1.24	21.50	38.39	A	
Do	100	1.24	21.50	38.39	A	} 38.09
Do	100	1.24	21.00	37.50	A	
Mar. 1, 1909	100	1.18	18.50	33.08	B	
Do	100	1.18	18.00	32.14	B	} 33.03
Do	100	1.24	19.00	33.93	B	
Do	100	1.24	17.75	31.69	C	
Do	100	1.18	17.50	31.25	C	} 31.40
Mar. 2	100	1.24	17.50	31.25	C	

P=1.911A+0.58B−1.411C=45.00 kilograms per square centimeter.
V=15,000 cubic centimeters.   S=1.28   W=100 grams.

$M = \dfrac{VPS}{W} = 8,235$ kilograms per square centimeter (117,121 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE.

Date, June 22, 1909.

	Grams.
Solid	79.7
Liquid (water)	14.5
Gaseous	88.4

GASEOUS PRODUCTS OF COMBUSTION.

	Per cent by volume.
Carbon dioxide	51.4
Carbon monoxide	5.0
Hydrogen	2.2
Methane	.3
Nitrogen	41.1
	100.0

SOLID PRODUCTS OF COMBUSTION.

	Per cent.
Soluble (sodium carbonate)	79.43
Insoluble (calcium carbonate, trace of unburned carbonaceous matter, and carbonates and oxides of copper, iron, and tin)	20.57
	100.00

GASEOUS PRODUCTS OF COMBUSTION FROM 200 GRAMS OF THE EXPLOSIVE AND 12.4 GRAMS OF PAPER WRAPPER.

[A. L. Hyde, analyst.]

	Per cent.
Carbon dioxide	27.3
Carbon monoxide	26.9
Hydrogen	18.0
Methane	.4
Nitrogen	27.4
	100.0

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 100 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	*° C.*	*Calories.*
Mar. 2	81.95	1.310	1,216.3
Mar. 3	81.90	1.318	1,223.1
Do	81.75	1.322	1,224.8

Average large calories per kilogram of explosive, 1,221.4.

COMPRESSION OF SMALL LEAD BLOCKS.

Date (1909).	Weight of charge.	Height.		Compression.
		Before explosion.	After explosion.	
	Grams.	*Millimeters.*	*Millimeters.*	*Millimeters.*
Feb. 24	100	64.0	(a)	
Mar. 3	25	64.0	48.0	16.0

a Top of block shattered.

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	*Cubic centimeters.*	*Cubic centimeters.*	*° C.*
Oct. 16	62	337	275	15
Do	62	344	282	15
Do	62	338	276	15

Average expansion of bore hole, 278 cubic centimeters (16.96 cubic inches).

2406°—Bull. 15—12——12

CHAPTER VII.

RESULTS OF TESTS WITH BLACK BLASTING POWDER.

By CLARENCE HALL and S. P. HOWELL.

FFF BLACK BLASTING POWDER

Explosive, FFF black blasting powder.
Class, black powder.
Apparent specific gravity of prepared cartridge by sand, 1.25.
Color, black.
Consistency, granular.
Unit deflective charge, using 1 pound of tamping, as determined by the ballistic pendulum:

Date, November 26, 1909.
Unit swing on this date, 2.91 inches.
Weight of charge, in grams, 460, 460, 460.
Swing, in inches, 2.87, 2.90, 3.00.
Average swing, in inches, 2.92.

$$2.92 : 2.91 :: 460 : (458).$$

Therefore the unit deflective charge of FFF black blasting powder, using 1 pound of tamping, is 458 grams.

Unit deflective charge, using 2 pounds of tamping, as determined by the ballistic pendulum:

Date, February 25, 26, 27, 1909.
Unit swing on these dates, 3.01 inches.
Weight of charge, in grams, 375, 375, 375.
Swing, in inches, 3.03, 3.03, 3.00.
Average swing, in inches, 3.02.

$$3.02 : 3.01 :: 3.75 : (374).$$

Therefore the unit deflective charge of FFF black blasting powder, using 2 pounds of tamping, is 374 grams.

During the period covered by this bulletin many tests were run with various grades of black blasting powder and in every case an ignition resulted, whether the shot was made into gas and air, dust and air, or gas, dust, and air.

RATE OF BURNING.

Electric igniter used.

Date (1909).	Distance between spark points.	Peripheral speed of drum per second.	Rate of burning per second.
	Millimeters.	*Meters.*	*Meters.*
Apr. 22..	53.26	25	469.4

Rate of burning 469.4 meters (1,540 feet) per second. This test was made with an FF black blasting powder.

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FLAME TEST.

Peripheral speed of film, 0.40 meter per second.

Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
	Millimeters.	*Inches.*	*Millimeters.*	*Milliseconds.*
Mar. 3	43.0	54.32	370.00	925.000

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.56 millimeter = 1 kilogram per square centimeter.

Date (1909).	Charge.	Specific gravity.	Height of curve.	Pressure per square centimeter.	Cooling surface.	Average pressure per square centimeter.
	Grams.		*Millimeters.*	*Kilograms.*		*Kilograms.*
Jan. 8	200	1.34	25.50	45.54	A	
Jan. 13	200	1.21	25.50	45.54	A	45.42
Do	200	1.22	25.50	45.54	A	
Do	200	1.21	25.25	45.02	A	
Mar. 18	200	1.33	22.50	40.18	B	
Mar. 19	200	1.35	23.25	41.52	B	41.63
Mar. 23	200	1.41	23.50	41.96	B	
Do	200	1.42	24.00	42.86	B	
Mar. 19	200	1.52	22.00	39.29	C	
Do	200	1.47	22.00	39.29	C	39.85
Mar. 20	200	1.41	22.75	40.63	C	
Do	200	1.44	22.50	40.18	C	

P=1.911 A+0.5B−1.411 C.=51.38 kilograms per square centimeter.

V=15,000 cubic centimeters.   S=1.25.   W=200 grams.

$M = \dfrac{VPS}{W} = 4{,}817$ kilograms per square centimeter (68,509 pounds per square inch).

PRODUCTS OF COMBUSTION FROM 300 GRAMS OF THE EXPLOSIVE.

Date, March 16, 1909.

	Grams.
Solid	126.9
Liquid (water)	4.1
Gaseous	154.4

GASEOUS PRODUCTS OF COMBUSTION.

	Per cent by volume.
Carbon dioxide	49.7
Carbon monoxide	10.8
Hydrogen sulphide	8.7
Hydrogen	1.8
Methane	.6
Nitrogen	28.4
	100.0

SOLID PRODUCTS OF COMBUSTION.

	Per cent.
Soluble (sodium carbonate and suphide with small amounts of sulphate and sulphite)	91.2
Insoluble (carbon and sulphur in combination with iron and copper)	8.8
	100.0

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge, 200 grams.

Date (1909).	Weight of water.	Rise in temperature.	Heat developed per kilogram.
	Kilograms.	*°C.*	*Calories.*
Apr. 1...	82.77	1.640	769.1
Apr. 2...	82.11	1.738	809.6

Average large calories per kilogram of explosive, 789.4.

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCK.

Charge, 10 grams.

Date (1909).	Volume of bore hole.		Expansion of bore hole.	Temperature of block.
	Before shot.	After shot.		
	Cubic centimeters.	*Cubic centimeters.*	*Cubic centimeters.*	*°C.*
Dec. 6..	62	90	28	15
Do..	62	91	29	15
Do..	62	92	30	15

Average expansion of bore hole, 29 cubic centimeters.

The average expansion of bore hole from three tests made December 6, 1909, with No. 7 electric detonators, gave 5 cubic centimeters. The detonators were placed in a cartridge of sand and then tamped in the usual manner.

CHAPTER VIII.

RESULTS OF TESTS OF FOUR FOREIGN EXPLOSIVES.

By CLARENCE HALL and S. P. HOWELL.

After the apparatus for testing explosives had been installed at the Pittsburgh testing station, comparative tests were made with the different classes of so-called safety powders then on the market. The results of these tests indicated that several of the explosives would pass the gallery tests when the charge was stemmed, but the highest limit charge established with unstemmed shots when fired in the presence of a mixture of gas and air containing 8 per cent of gas (methane and ethane) was only 100 grams. Repeated tests demonstrated that this limit charge could not be increased, even when loaded under special charging densities.

One of the explosives tested was similar in composition to a foreign "permitted" explosive of the nitroglycerin class, which was said to have a limit charge of 900 grams. Through the courtesy of one of the foreign testing stations, samples of this permitted explosive and of three other foreign permitted explosives were procured for comparative tests. The following chapter gives in detail the results of tests of these four explosives. Owing to the short time allotted, several of the tests were modified as to the number of trials; otherwise tests were conducted and methods were followed under approximately the same procedure as that of the foreign stations. It is to be noted that the highest limit charge established with the foreign explosives was only 50 grams. It was found after repeated tests that the limit charge could not be increased, even when loaded under special charging densities.

The results of tests indicated that all of the foreign explosives would pass the British tests, but would probably fail to pass the Continental tests. Only one of the explosives submitted, namely, explosive "D," would pass the test requirements requisite for its being placed in the United States permissible list.

The conclusions drawn were that the natural gas used at the Pittsburgh testing station was more sensitive than the pit gas used abroad, and that for this reason the percentage of gas used at Pittsburgh would necessarily have to be reduced in order to obtain results comparable with those obtained abroad.

For convenience in reporting the results of tests the four foreign explosives are here designated explosives A, B, C, and D.

Explosive A.
Class, black powder.
Physical examination:
    Diameter of cartridge, 3.9 centimeters (1.5 inches). .
    Length of cartridge, 5.8 centimeters (2.25 inches).
    Average weight, 92 grams.
    The compressed pellet had been dipped.
    Apparent specific gravity of cartridge by sand, 1.36.
    Color of explosive, black and white, speckled.
    Consistency, compressed pellet.
Explosive B.
Class, ammonium nitrate.
Physical examination:
    Diameter of cartridge, 4.0 centimeters (1.5 inches).
    Length of cartridge, 9.5 centimeters (3.65 inches).
    Average weight, 116 grams.
    Cartridge had been redipped.
    Apparent specific gravity of cartridge by sand, 0.79.
    Color of explosive, yellow.
    Consistency, granular.
Explosive C.
Class, ammonium nitrate, containing nitroglycerin.
Physical examination:
    Diameter of cartridge, 4.2 centimeters (1.67 inches).
    Length of cartridge, 8.0 centimeters (3.25 inches).
    Average weight, 113.5 grams.
    Cartridge had been redipped.
    Apparent specific gravity of cartridge by sand, 0.95.
    Color of explosive, buff.
    Consistency, dry, fibrous.
Explosive D.
Class, nitroglycerin.
Physical examination:
    Diameter of cartridge, 4.0 centimeters (1.5 inches).
    Length of cartridge, 19.0 centimeters (7.5 inches).
    Average weight, 188 grams.
    Cartridge had not been redipped.
    Apparent specific gravity of cartridge by sand, 0.68.
    Color of explosive, straw.
    Consistency, fine, fibrous.

CHEMICAL ANALYSES.

Chemical analyses of these four explosives resulted as follows:

EXPLOSIVE A.

Moisture	0. 46
Potassium nitrate	65. 31
Sulphur	2. 63
Charcoal	19. 52
Paraffin	3. 35
Starch	8. 73
	100. 00

Ash 0.97.

EXPLOSIVE B.

Moisture	0. 17
Ammonium nitrate	89. 08
Trinitro-toluene	6. 56
Mononitro-naphthalene	4. 19
	100. 00

EXPLOSIVE C.

Moisture	0. 60
Nitroglycerin	8. 37
Ammonium nitrate	83. 14
Wood pulp	4. 65
Nitrotoluol	3. 24
	100. 00

Ash 0.098.

EXPLOSIVE D.

Moisture	4. 05
Nitroglycerin	24. 92
Barium nitrate	4. 42
Wood pulp	34. 60
Potassium nitrate	25. 37
Starch	6. 64
	100. 00

Ash 0.14.

PRODUCTS OF COMBUSTION FROM 200 GRAMS OF EACH EXPLOSIVE (WITHOUT PAPER WRAPPER).

Explosives.	Date (1909).	Test No.	Products of combustion.		
			Gaseous.	Solid.	Liquid (water).
			Grams.	*Grams.*	*Grams.*
A	June 1	P 200	81. 4	118. 3	1. 6
B	Apr. 28	P 147	111. 9	. 0	84. 2
C	May 1	P 153	111. 8	0. 0	85. 7
D	May 12	P 171	130. 3	49. 0	12. 4

GASEOUS PRODUCTS OF COMBUSTION, PERCENTAGE BY VOLUME.

Explosives.	Date (1909).	Test No.	Products.						
			H_2S.	CO_2.	CO.	O_2.	H_2.	CH_4.	N_2.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
A	June 1	P 200	1. 1	13. 9	41. 8	. 0	23. 6	2. 8	16. 8
B	Apr. 28	P 147	. 0	26. 7	. 0	3. 2	. 0	0	70. 1
C	May 1	P 153	. 0	30. 8	. 0	1. 5	. 0	0	67. 7
D	May 12	P 171	. 0	18. 9	36. 3	. 0	29. 1	5. 8	9. 9

SOLID PRODUCTS OF COMBUSTION, PERCENTAGE BY WEIGHT.

Explosives.	Date (1909).	Test No.	Products of combustion.	
			Soluble.	Insoluble.
A	June 1	P 200	87. 84	12. 16
D	May 12	P 171	76. 10	23. 90

LARGE CALORIES DEVELOPED BY 1 KILOGRAM OF THE EXPLOSIVE.

Charge A = 200 grams; B, C, and D = 100 grams.

Explosives.	Date (1909).	Test No.	Weight of water.	Rise in temperature.	Heat developed per kilogram.	Average heat developed per kilogram.
			Kilos.	*°C.*	*Calories.*	*Calories.*
A	Sept. 3	106	81.90	1.342	623	
	3	107	81.70	1.315	609	622.7
	4	108	81.60	1.375	636	
B	June 3	79	82.73	1.290	1,208	
	3	80	82.73	1.294	1,211	1,197.0
	3	81	82.73	1.252	1,172	
C	Sept. 9	112	81.60	1.345	1,244	
	9	113	82.25	1.328	1,237	1,245.0
	9	114	83.35	1.330	1,254	
D	Sept. 8	110	81.70	.626	575	
	8	111	81.75	.617	567	570.7
	10	115	81.95	.619	570	

COMPRESSION OF SMALL LEAD BLOCKS.

Charge, 100 grams.

Explosives.[a]	Date (1909).	Test No.	Height before explosion.	Height after explosion.	Compression.
			Millimeters.	*Millimeters.*	*Millimeters.*
B	Apr. 22	B 111	63.7	55.5	8.2
	22	B 112	63.7	55.8	7.9
	22	B 113	63.7	56.0	7.7
C	22	B 114	63.5	46.5	17.0
	22	B 115	63.5	47.0	16.5
	22	B 116	63.5	46.5	17.0
D	22	B 117	63.0	53.0	10.0
	22	B 118	63.0	52.8	10.2
	22	B 119	63.0	53.0	10.0

[a] This test was not run on explosive A, as it was a slow-burning explosive.

The average compression is as follows:

Explosive B, 7.93 millimeters (0.31 inch).
Explosive C, 16.83 millimeters (0.66 inch).
Explosive D, 10.07 millimeters (0.40 inch).

EXPANSION OF BORE HOLE OF TRAUZL LEAD BLOCKS.

Charge, 10 grams.

Explosives.[a]	Date (1909).	Test No.	Volume of bore hole before shot.	Volume of bore hole after shot.	Expansion of bore hole.
			Cubic centimeters.	*Cubic centimeters.*	*Cubic centimeters.*
B	Apr. 5	A 154	62	280	218
	5	A 155	62	287	225
	5	A 156	62	287	225
C	5	A 157	62	340	278
	5	A 158	62	372	310
	5	A 159	62	378	316
D	5	A 160	62	214	152
	5	A 161	62	228	166
	5	A 162	62	212	150

[a] This test was not made with explosive A, as it was slow burning.

The average expansions follow:

Explosive B, 223 cubic centimeters (13.60 cubic inches).
Explosive C, 301 cubic centimeters (18.36 cubic inches).
Explosive D, 156 cubic centimeters (9.52 cubic inches).

BALLISTIC PENDULUM TESTS.

The standard Woolwich swing was taken as the swing produced by 295 grams (10⅜ ounces) of explosive A, tamped with 2 pounds of dry fire clay. The standard (Woolwich) swing of explosive A and the computed swings of explosives B, C, and D follow:

SWINGS OF EXPLOSIVES A, B, C, AND D.

Explosives.	Date (1909).	Charge.	Swing.	Average swing.	Woolwich disruptive charge.
		Grams.	*Inches.*	*Inches.*	*Grams.*
A	Mar. 29	295	1.71		
	29	295	1.61	1.68	295
	29	295	1.73		
B	29	140	1.62		
	29	140	1.62	1.63	144
	29	140	1.64		
C	29	110	1.38		
	29	110	1.35	1.35	137
	29	110	1.33		
D	30	200	1.72		
	30	200	1.63	1.69	199
	30	200	1.71		

NOTE.—Swing figures for explosive A are results of tests; swings of explosives B,C,and D computed.

UNIT DEFLECTIVE CHARGE AS DETERMINED BY THE BALLISTIC PENDULUM.

Explosives.	Date (1909).	Charge.	Swing.	Average swing.	Unit deflective charge.
		Grams.	*Inches.*	*Inches.*	*Grams.*
Pittsburgh testing station 40 per cent standard dynamite	Mar. 30	227	2.675		
	30	227	2.675	a2.70	227
	30	227	2.765		
A	30	400	2.55		
	30	400	2.58	2.55	420
	30	400	2.51		
Pittsburgh testing station 40 per cent standard dynamite	31	227	2.70		
	31	227	2.82	2.76	227
	31	227	2.75		
B	31	205	2.70		
	31	205	2.75	2.76	205
	31	205	2.84		
C	31	195	2.65		
	31	195	2.64	2.67	202
	31	195	2.73		
D	31	295	2.77		
	31	295	2.65	2.73	298
	31	295	2.78		

a 2.68 was used in computing unit deflective charge for explosive A.

In all of the tests in gas and dust gallery No. 1 the following igniter and detonators were used:

Explosive A, electric igniter.

Explosive B, electric detonator No.7.

Explosive C, electric detonator No. 6.

Explosive D, electric detonator No. 6.

THE BELGIAN TEST (MODIFIED) FOR DETERMINATION OF THE LIMIT CHARGE IN A MIXTURE OF GAS AND AIR CONTAINING 8 PER CENT OF METHANE AND ETHANE.

Limit charge is established if five shots fail to ignite the mixture.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		Grams.	*Per cent.*	
A	Mar. 29	50	8.20	Ignition.
	29	25	8.18	Do.
	29	25	8.08	Do.
B	29	200	8.08	Do.
	29	50	8.02	No ignition.
	29	125	8.02	Ignition.
	29	100	7.87	Do.
	29	75	7.89	Do.
	29	50	7.83	Do.
	29	25	8.01	Do.
C	29	200	8.01	Do.
	29	100	7.82	Do.
	29	25	7.77	Do.
D	29	25	7.86	No ignition.
	29	100	7.89	Ignition.
	29	50	8.01	No ignition.
	29	75	8.08	Ignition.
	29	50	8.08	No ignition.
	29	50	8.13	Do.
	29	50	8.00	Do.
	29	50	8.11	Do.

The limit charges for this test are established as follows:

                                                 Grams.

Explosive A... 0

Explosive B... 0

Explosive C... 0

Explosive D... 50

WOOLWICH TEST (MODIFIED).

Five shots with the standard (Woolwich) charge, in its original wrapper, shall be fired with 12 inches of clay tamping (explosive A hammered in; B, C, and D tamped by hand) at a gallery temperature of 77° F. into a mixture of gas and air containing 8 per cent of methane and ethane. An explosive passes this test if all five shots fail to ignite the mixture.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		Grams.	*Per cent.*	
A	Mar. 30	295	7.92	No ignition.
	30	295	8.03	Do.
	30	295	8.12	Do.
	30	295	7.95	Do.
	30	295	8.15	Do.
B	30	144	7.96	Do.
	30	144	7.96	Do.
	30	144	7.87	Do.
	30	144	7.87	Do.
	30	144	7.84	Do.
C	30	137	7.90	Do.
	30	137	7.86	Do.
	30	137	7.86	Do.
	30	137	7.96	Do.
	30	137	7.81	Do.
D	30	199	7.98	Do.
	30	199	8.15	Do.
	30	199	8.15	Do.
	30	199	8.16	Do.
	30	199	8.18	Do.

The explosives A, B, C, and D passed this test.

WOOLWICH TEST (MODIFIED).

Five shots with three-quarters of the standard (Woolwich) charge, in its original wrapper, shall be fired with 9 inches of clay tamping (explosive A hammered in; B, C, and D by hand) at a gallery temperature of 77° F., into a mixture of gas and air containing 8 per cent of methane and ethane. An explosive passes this test if all five shots fail to ignite the mixture.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		Grams.	*Per cent.*	
A	Mar. 30	221	8.13	No ignition.
	30	221	8.13	Do.
	30	·221	8.13	Do.
	30	221	8.18	Do.
	30	221	8.11	Do.
B	30	108	7.86	Do.
	30	108	7.84	Do.
	30	108	7.86	Do.
	30	*a*144	7.76	Do.
	30	108	7.92	Do.
C	30	103	8.71	Do.
	30	103	8.18	Do.
	31	103	8.24	Do.
	31	103	8.24	Do.
	31	103	8.23	Do.
D	31	150	8.12	Do.
	31	150	8.25	Do.
	31	150	8.25	Do.
	31	150	8.25	Do.
	31	150	8.12	Do.

a Weight of charge was greater than unit disruptive charge.

The explosives A, B, C, and D passed this test.

BUREAU OF MINES TESTS.

GAS AND DUST GALLERY No. 1.

Test 1, except that 5 shots are made instead of 10.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		Grams.	*Per cent.*	
A	Apr. 20	420	8.05	Ignition.*a*
B	3	205	8.27	No ignition.
	3	205	8.11	Do.
	3	205	8.34	Do.
	3	205	8.33	Do.
	3	205	8.00	Do.
C	4	202	7.78	Do.
	4	202	8.12	Ignition.
	4	202	8.12	No ignition.
	24	202	8.12	Do.
	24	202	7.84	Ignition.
D	24	296	8.01	No ignition.
	24	296	7.89	Do.
	24	296	7.89	Do.
	24	296	7.89	Do.
	24	296	7.78	Do.

a Bore reduced to 1½ inches for this test by using a 1½-inch inside diameter pipe in bore hole.

Explosives B and D passed this test.
Explosives A and C failed to pass this test.

GAS AND DUST GALLERY No. 1.

Same as test 2, except that 5 shots are made instead of 10.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		Grams.	*Per cent.*	
A	Apr. 4	420	4.06	No ignition.
	4	420	3.98	Do.
	4	420	4.06	Do.
	4	420	3.98	Do.
	4	420	4.06	Do.
B	3	205	4.06	Do.
	3	205	4.23	Do.
	3	205	4.23	Do.
	3	205	4.23	Do.
	3	205	4.23	Do.
C	3	202	4.06	Do.
	3	202	3.98	Do.
	3	202	3.98	Do.
	3	202	4.06	Do.
	3	202	4.06	Do.
D	3	296	3.98	Do.
	3	296	3.98	Do.
	3	296	4.06	Do.
	3	296	3.89	Do.
	3	296	3.89	Do.

The explosives A, B, C, and D passed this test.

GAS AND DUST GALLERY No. 1.

Same as test 3, except that 5 shots are used instead of 10.

Explosives.	Date (1909).		Weight of charge.	Result.
			Grams.	
A	Apr.	2	420	No ignition.
		2	420	Do.
		2	420	Do.
		2	420	Do.
		2	420	Do.
B		2	205	Do.
		2	205	Do.
		2	205	Do.
		2	205	Do.
		2	205	Do.
C		2	202	Do.
		2	202	Do.
		2	202	Do.
		2	202	Do.
		2	202	Do.
D		2	298	Do.
		2	298	Do.
		2	298	Do.
		2	298	Do.
		2	298	Do.

The explosives A, B, C, and D passed this test.

GAS AND DUST GALLERY No. 1.

Test 4.

Explosives.	Date (1909).		Weight of charge.	Methane plus ethane.	Result.
			Grams.	*Per cent.*	
A	Mar.	31	50	4.23	No ignition.
		31	100	4.11	Do.
		31	200	4.24	Ignition.
		31	200	(a)	
		31	150	4.19	Do.
		31	125	4.19	Do.
		31	100	4.04	No ignition.
		31	100	4.05	Do.
		31	100	4.21	Do.
		31	100	4.20	Do.
B		31	200	4.02	Do.
		31	300	4.02	Ignition.
		31	250	3.98	Do.
		31	225	4.19	No ignition.
		31	225	4.02	Ignition.
		31	200	4.02	Do.
		31	175	4.02	Do.
		31	175	4.04	Do.
		31	150	4.13	No ignition.
		31	150	4.13	Do.
		31	150	4.05	Ignition.
		31	125	3.96	Do.
		31	100	4.02	Do.
		31	75	4.11	No ignition.
		31	75	4.02	Do.
	Apr.	1	75	4.02	Do.
		1	75	4.11	Do.
		1	75	4.11	Do.

a No gas or dust used, in order to note effect of charge alone. Flame in no doorway, but in window No. 1.

GAS AND DUST GALLERY No. 1—Continued.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		Grams.	*Per cent.*	
C	Apr. 1	200	4.11	Ignition.
	1	100	4.11	Do.
	1	50	4.18	No ignition.
	1	75	4.14	Do.
	1	75	3.98	Do.
	1	75	4.11	Do.
	1	75	4.07	Do.
	1	75	4.07	Do.
D	1	100	4.07	Do.
	1	200	4.14	Do.
	1	300	4.07	Do.
	1	500	4.07	Do.
	1	700	4.14	Do.
	4	1,000	4.07	Do.
	21	1,000	3.96	Do.
	21	1,000	4.07	Do.
	21	1,000	3.96	Do.
	21	1,000	4.05	Do.

For this test the following limit charges were established: Grams.

Explosive A... 100

Explosive B... 75

Explosive C... 75

Explosive D (the capacity of the cannon)................... 1,000

GAS AND DUST GALLERY No. 1.

Test 5.

Explosives.	Date (1909).	Weight of charge.	Methane plus ethane.	Result.
		Grams.	*Per cent.*	
A	Apr. 1	200	2.03	No ignition.
	1	300	1.96	Do.
	1	400	2.20	Do.
	6	600	2.68	Ignition.
	6	500	2.03	Do.
	6	450	2.03	Do.
	6	425	2.03	Do.
	6	400	2.04	Do.
	6	375	2.04	Do.
	6	350	2.04	Do.
	6	300	2.03	No ignition.
	6	325	2.03	Ignition.
	14	300	2.26	Do.
	14	250	2.26	No ignition.
	14	275	2.46	Do.
	15	275	2.17	Do.
	15	275	2.26	Do.
	15	275	2.27	Do.
	15	275	2.26	Do.
B	4	200	2.21	Do.
	4	300	2.29	Do.
	4	400	2.29	Ignition.
	4	350	2.21	Do.
	4	325	2.10	No ignition.
	4	325	2.03	Ignition.
	4	300	2.03	Do.
	4	275	2.04	Do.
	4	250	2.03	No ignition.
	4	250	2.03	Do.
	4	250	2.03	Do.
	4	250	2.05	Do.
	4	250	2.03	Do.

Gas and Dust Gallery No. 1—Continued.

Explosives.	Date (1909).		Weight of charge.	Methane plus ethane.	Result.
			Grams.	*Per cent.*	
C	Apr.	1	400	2.03	Ignition.
		1	200	2.04	No ignition.
		1	300	2.03	Do.
		2	350	1.97	Do.
		2	375	2.11	Ignition.
		2	350	2.11	No ignition.
		2	350	2.03	Do.
		2	350	2.03	Ignition.
		2	325	2.05	No ignition.
		2	325	2.03	Ignition.
		2	300	2.04	Do.
		2	275	2.04	No ignition.
		2	275	2.03	Do.
		2	275	2.13	Do.
		2	275	2.11	Do.
		2	275	2.03	Do.
D		4	1,000	2.03	Do.

For this test the following limit charges were established:

Grams.

Explosive A 275

Explosive B 250

Explosive C 275

Explosive D (the capacity of the cannon) 1,000

RATE OF DETONATION.

Diameter of cartridge used, 1¼ inches.
Electric detonator No. 7 used.

Explosives.	Date (1909).		Distance between spark points.	Peripheral speed of of drum.	Rate of detonation.
			Millimeters.	*Meters per second.*	*Meters per second.*
A	Rate of burning too slow to give interruption sparks.				
B	May	6	14.70	43	2,925
		7	14.71	43	2,923
C		5	11.26	43	3,819
		6	11.09	43	3,877
D		7	17.06	43	2,520
		7	16.18	43	2,658

The average rates of detonations of the explosives are as follows:

Explosive B, 2,924 meters per second (9,590 feet per second).
Explosive C, 3,848 meters per second (12,620 feet per second).
Explosive D, 2,589 meters per second (8,490 feet per second).

FLAME TEST.

Peripheral speed of film $\frac{1}{15}$ meter per second for explosive A; 20 meters per second for explosives B, C, and D.

Explosives.	Date (1909).	Height of photograph.	Height of flame.	Duration distance.	Duration of flame.
		Milli-meters.	*Inches.*	*Milli-meters.*	*Milli-seconds.*
A..	May 17	48.00	60.63	322.00	1,030.400
B..	3	23.50	29.68	12.25	.612
	3	22.25	28.11	10.25	.512
	3	23.25	29.37	13.00	.650
C..	Apr. 28	21.50	27.16	8.50	.425
	28	21.25	26.84	8.25	.412
	28	21.50	27.16	7.50	.375
D..	28	15.00	18.95	6.75	.338
	28	15.00	18.95	7.75	.388
	28	15.75	19.89	6.75	.338

The average heights and durations of flame are as follows:
Explosive A, height 60.63 inches; duration 1030.400 milliseconds.
Explosive B, height 29.05 inches; duration .591 milliseconds.
Explosive C, height 27.05 inches; duration .404 milliseconds.
Explosive D, height 19.26 inches; duration .355 milliseconds.

IMPACT MACHINE.

Explosives.	Date (1909).	Distance of fall.	Number of falls.	Result.
		Centi-meters.		
A..	Sept. 7	60	1	No explosion.
	7	80	1	Do.
	7	90	1	Do.
	7	100	5	Do.
B..	8	42	1	Do.
	8	50	1	Do.
	8	60	1	Do.
	8	70	1	Do.
	8	80	1	Do.
	8	90	1	Do.
	8	100	5	Do.
C..	8	34	1	Explosion.
	8	32	1	Do.
	8	31	1	No explosion.
	8	31	1	Explosion.
	8	30	5	No explosion.
D..	24	50	1	Explosion.
	24	45	1	Do.
	24	40	1	Do.
	24	35	1	Do.
	24	30	1	Do.
	24	25	1	Do.
	24	20	1	Do.
	24	15	1	Do.
	24	10	1	No explosion.
	24	14	1	Explosion.
	24	13	5	No explosion.

The maximum heights that will cause no explosion are established as follows:
Explosive A, 100 centimeters (39.37 inches), capacity of machine.
Explosive B, 100 centimeters (39.37 inches), capacity of machine.
Explosive C, 30 centimeters (11.81 inches).
Explosive D, 13 centimeters (5.12 inches).

EXPLOSION BY INFLUENCE TEST.

Explosives.a	Date (1909).	Weight of cartridge.	Distance separating cartridges.	Result (upper cartridge).
		Grams.	Inches.	
B..	June 2	155	2	No explosion.
	2	155	1	Do.
	3	155	½	Do.
	Sept. 8	155	½	Partial explosion.
	9	155	½	
	9	155	½	No explosion.
	13	155	½	Do.
C..	9	153	2	Explosion.
	24	153	4	No explosion.
	24	153	3	Do.
	24	153	2	Explosion.
	24	153	3	No explosion.
	24	153	3	Do.
D..	4	90	6	Do.
	4	90	3	Explosion.
	7	90	5	No explosion.
	7	90	4	Do.
	7	90	4	Do.
	7	90	4	Do.

a This test was not run with explosive A, as it was impracticable to make it under standard-size cartridges

The minimum distances at which there was no explosion by influence are established as follows:

	Inches.
Explosive B...	0
Explosive C...	3
Explosive D...	4

THEORETICAL MAXIMUM PRESSURE DEVELOPED IN OWN VOLUME AS DETERMINED BY BICHEL PRESSURE GAGE.

Indicator spring, 0.4 millimeter = 1 kilogram per square centimeter.

Special conditions for explosive A; the initial pressure was 1 atmosphere, and electric igniters were used.

Explosives.	Date (1909).	Test No.	Charge.	Specific gravity.	Height of curve.	Pressure.	Cooling surface.	Average pressure.
			Grams.		Milli-meters.	Kilograms per square centimeter.		Kilograms per square centimeter.
A..............	May 22	P 189	300	1.38	26.00	65.00	A	
	22	P 190	300	1.38	25.50	63.75	A	} 64.17
	22	P 191	300	1.38	25.50	63.75	A	
	22	PP 199	300	1.38	24.00	60.00	B	
	22	PP 200	300	1.38	24.75	61.88	B	} 61.25
	22	PP 201	300	1.38	24.75	61.88	B	
	24	PP 202	300	1.38	24.50	61.25	C	
	24	PP 203	300	1.38	24.80	62.00	C	} 62.13
	24	PP 204	300	1.38	25.25	63.13	C	
B..............	17	P 176	200	.88	44.25	110.63	A	
	17	P 178	200	.88	43.00	107.50	A	} 107.92
	17	P 179	200	.88	42.25	105.63	A	
	13	PP 181	200	.92	40.00	100.00	B	
	13	PP 182	200	.88	40.00	100.00	B	} 99.58
	14	PP 183	200	.88	39.50	98.75	B	
	14	PP 184	200	.88	38.25	95.63	C	
	15	PP 185	200	.88	38.00	95.00	C	} 96.46
	17	PP 186	200	.88	39.50	98.75	C	

Theoretical Maximum Pressure Developed in Own Volume as Determined by Bichel Pressure Gage—Continued.

Explosives.	Date (1909).	Test No.	Charge.	Specific gravity.	Height of curve.	Pressure.	Cooling surface.	Average pressure.
			Grams.		*Milli-meters.*	*Kilograms per square centimeter.*		*Kilograms per square centimeter.*
C...............	May 18	P 180	200	.96	41.25	103.13	A	103.13
	18	P 181	200	.96	41.25	103.13	A	
	18	P 182	200	.96	41.25	103.13	A	
	19	PP 190	200	.96	38.25	95.63	B	
	19	PP 191	200	.96	38.00	95.00	B	94.38
	19	PP 192	200	.96	37.00	92.50	B	
	18	PP 187	200	.96	36.00	90.00	C	
	18	PP 188	200	.96	36.50	91.25	C	90.63
	19	PP 189	200	.96	36.25	90.63	C	
D...............	21	P 186	200	.76	24.50	61.25	A	
	21	P 187	200	.76	24.60	61.50	A	61.33
	21	P 188	200	.76	24.50	61.25	A	
	20	PP 193	200	.76	23.50	58.75	B	
	20	PP 194	200	.76	23.25	58.13	B	58.33
	20	PP 195	200	.76	23.25	58.13	B	
	20	PP 196	200	.76	22.50	56.25	C	
	20	PP 197	200	.76	22.50	56.25	C	56.25
	20	PP 198	200	.76	22.50	56.25	C	

Computations for the respective explosives, established as the result of the above tests, were as follows:

Explosive A: $P=1.911A+0.5B-1.411C=65.59$ kilos per square centimeter. $V=15,000$ cubic centimeters. $S=1.36$. $W=300$ grams. $M=\frac{VPS}{W}=4,460.12$ kilos per square centimeter (63,440 pounds per square inch).

Explosive B: $P=1.911A+0.5B-1.411C=119.92$ kilos per square centimeter. $V=15,000$ cubic centimeters. $S=0.79$. $W=200$ grams. $M=\frac{VPS}{W}=7,105.26$ kilos per square centimeter (101,070 pounds per square inch).

Explosive C: $P=1.911A+0.5B-1.411C=116.39$ kilos per square centimeter. $V=15,000$ cubic centimeters. $S=0.95$. $W=200$ grams. $M=\frac{VPS}{W}=8,292.79$ kilos per square centimeter (117,960 pounds per square inch).

Explosive D: $P=1.911A+0.5B-1.411C=67.00$ kilos per square centimeter. $V=15,000$ cubic centimeters. $S=0.68$. $W=200$ grams. $M=\frac{VPS}{W}=3,417.00$ kilos per square centimeter (48,600 pounds per square inch).

APPENDIX.

BUREAU OF MINES TESTS OF EXPLOSIVES.

CONDITIONS UNDER WHICH EXPLOSIVES ARE TESTED.

The following conditions under which the Bureau of Mines tests explosives to determine whether they shall be placed on its list of permissible explosives were approved January 3, 1911:

1. The manufacturer is to deliver to the Bureau of Mines, Fortieth and Butler Streets, Pittsburgh, Pa., three weeks prior to date set for tests, 100 pounds of each explosive that he desires to have tested. He is to be responsible for the care, handling, and delivery of this material to the testing station, and he is to have a representative present during the tests. In order to avoid duplication of work, it is requested that the smallest size of cartridge that the manufacturer intends to place on the market be sent for these tests.

2. No one is to be present at or participate in these tests except the necessary Government officers at the experiment station, their assistants, and the representative of the manufacturer of the explosives to be tested.

3. These tests will be made in the order of the receipt of the applications for them, provided the necessary quantity of the explosive is delivered at the testing station by the date set, of which date due notice will be given by the Bureau of Mines.

4. A list of the explosives which pass certain requirements satisfactorily will be furnished to the State mine inspectors in the several States and will be made public in such manner as may be considered desirable.

5. The details of results of tests are to be considered confidential by the manufacturer and are not to be made public prior to official publication by the Bureau of Mines.

6. From time to time field samples of permissible explosives will be collected, and tests will be made of these explosives as they are supplied for use in coal mines in the various States.

TEST REQUIREMENTS FOR EXPLOSIVES.

The following test requirements for permissible explosives were approved on January 3, 1911:

The tests will be made by the engineers of the United States mining experiment station at Pittsburgh, Pa., in gas and dust gallery No. 1. The charge of explosive to be fired in tests 1, 2, and 3 shall be equal in deflective power, as determined by the ballistic pendulum, to one-half pound (227 grams) of 40 per cent nitroglycerin dynamite in its original wrapper, of the following formula:

	Per cent.
Nitroglycerin	40
Nitrate of soda (sodium nitrate)	44
Wood pulp	15
Carbonate of lime (calcium carbonate)	1
	100

Each charge shall be fired with an electric detonator (exploder or cap) strong enough to completely detonate or explode the charge, as recommended by the manufacturer. The explosive must be in such condition that the chemical and physical tests do not show any unfavorable results.

In order that the dust used in tests 2, 3, and 4 may be of the same quality, it is always taken from the same mine, ground to the same fineness, and used while still fresh.

The following are the gallery tests to which are subjected the explosives that the Bureau of Mines is asked to place in the list of permissible explosives:

Test 1. Ten shots each with the charge as described above, in its original wrapper, shall be fired, each tamped with 1 pound *a* of clay stemming, at a gallery temperature of 77° F., into a mixture of gas and air containing 8 per cent of gas (methane and ethane). An explosive is considered to have passed the test if no one of the 10 shots ignites this mixture.

Test 3. Ten shots each with the charge as described above, in its original wrapper, shall be fired, each tamped with 1 pound *a* of clay stemming, at a gallery temperature of 77° F., into 40 pounds of bituminous coal dust, 20 pounds of which is to be distributed uniformly on a wooden bench placed in front of the cannon and 20 pounds placed on side shelves in sections 4, 5, and 6. An explosive is considered to have passed the test if no one of the 10 shots ignites this mixture.

Test 4. Five shots each with 1½ pounds charge, in its original wrapper, shall be fired without stemming, at a gallery temperature of 77° F., into a mixture of gas and air containing 4 per cent of gas (methane and ethane) and 20 pounds of bituminous coal dust, 18 pounds of which is to be placed on shelves along the sides of the first 20 feet of the gallery and 2 pounds to be so placed that it will be stirred up by an air current in such manner that all or part of it will be suspended in the first division of the gallery. An explosive is considered to have passed the test if no one of the five shots ignites this mixture.

DEFINITION OF PERMISSIBLE EXPLOSIVE.

An explosive is called a permissible explosive when it is similar in all respects to the sample that passed certain tests by the national Bureau of Mines, and when it is used in accordance with the conditions prescribed by that bureau.

Subject to the conditions and provisions stated above, the following explosives are classed as permissible explosives:

Permissible explosives tested prior to January 1, 1911.

[Those reported in previous lists are marked with an asterisk (*).]

Brand.	Manufacturer.
*Aetna coal powder A	Aetna Powder Co., Chicago, Ill.
*Aetna coal dowder AA	Do.
*Aetna coal powder B	Do.
*Aetna coal powder C	Do.
*Aetna coal powder D	Do.
Bental coal powder No. 2	Independent Powder Co. of Missouri, Joplin, Mo.
*Bituminite No. 1	Jefferson Powder Co., Birmingham, Ala.
Bituminite No. 3	Do.
Bituminite No. 4	Do.
Bituminite No. 5	Do.
Bituminite No. 7	Do.
*Black Diamond No. 3	Illinois Powder Manufacturing Co., St. Louis, Mo.
*Black Diamond No. 4	Do.
*Carbonite No. 1	E. I. du Pont de Nemours Powder Co., Wilmington, Del.
*Carbonite No. 2	Do.
*Carbonite No. 3	Do.
*Carbonite No. 4	Do.
*Carbonite No. 1-L. F	Do.
*Carbonite No. 2-L. F	Do.
*Coalite No. 1	Potts Powder Co., New York City.
*Coalite No. 2-D	Do.
Coalite No. 2-D. L	Do.
Coalite No. 3-X	Do.
*Coal special No. 1	Keystone National Powder Co., Emporium, Pa.
*Coal special No. 2	Do.
*Coal special No. 3-C	Do.
Coal special No. 2-W	Do.
Coal special No. 3-W	Do.
Coal special No. 4	Do.
Coal special No. 5-L. F	Do.
*Collier powder No. 2	Do.
*Collier powder No. 4	Do.
*Collier powder No. 5	Do.
Collier powder No. 5 special	Do.
Collier powder No. 5-L. F	Do.
Collier powder No. X	Do.
Collier powder No. 2-L. F	Do.
Collier powder No. 3	Do.
Collier powder No. 6-L. F	Do.
Collier powder No. 8-L. F	Do.

a Two pounds of clay stemming are used with slow-burning explosives.

Permissible explosives tested prior to January 1, 1911—Continued.

Brand.	Manufacturer.
*Detonite special................................	The Detonite Co., Cincinnati, Ohio.
*Eureka No. 2-L. F...........................	G. R. McAbee Powder & Oil Co., Pittsburgh, Pa.
*Giant A low-flame dynamite...........	Giant Powder Co. (Consolidated), Giant, Cal.
*Giant B low-flame dynamite...........	Do.
*Giant C low-flame dynamite...........	Do.
*Hecla No. 2...............................	E. I. du Pont de Nemours Powder Co., Wilmington, Del.
*Kanite A.................................	W. H. Blumenstein Chemical Works, Pottsville, Pa.
*Masurite M. L. F........................	Masurite Explosives Co., Sharon, Pa.
*Meteor AXXO............................	E. I. du Pont Nemours Powder Co., Wilmington, Del.
*Mine-ite A..............................	Burton Powder Co., Pittsburgh, Pa.
*Mine-ite B..............................	Do.
*Monobel No. 1...........................	E. I. du Pont de Nemours Powder Co., Wilmington, Del.
*Monobel No. 2...........................	Do.
*Monobel No. 3...........................	Do.
Nitro low-flame No. 1...................	Nitro Powder Co., Kingston, N. Y.
Nitro low-flame No. 2...................	Do.
*Titanite No. 3-P........................	Waclark Titanite Explosive Co., Corry, Pa.
Titanite No. 7-P........................	Do.
Titanite No. 8-P........................	Do.
*Trojan coal powder A..................	Pennsylvania Trojan Powder Co., Allentown, Pa.
Trojan coal powder B..................	Do.
Trojan coal powder C..................	Do.
Trojan coal powder D..................	Do.
Trojan coal powder E..................	Do.
Trojan coal powder F..................	Do.
*Tunnelite No. 5.......................	G. R. McAbee Powder & Oil Co., Pittsburgh, Pa.
*Tunnelite No. 6.......................	Do.
*Tunnelite No. 7.......................	Do.
*Tunnelite No. 8.......................	Do.
*Tunnelite No. 6-L. F.................	Do.
*Tunnelite No. 8-L. F.................	Do.

The tests prescribed in Miners' Circular 2 as those a permissible explosive must have passed are those given above. But even the explosives that have passed those tests and are published as permissible explosives are to be considered as permissible explosives only when used under the following conditions:

1. That the explosive is in all respects similar to the sample submitted by the manufacturer for test.

2. That No. 6 detonators—preferably No. 6 electric detonators (double strength)—are used of not less strength than one gram charge, consisting by weight of 90 parts of mercury fulminate and 10 parts of potassium chlorate (or their equivalents), except for the explosives "Bental coal powder No. 2," "Detonite special," "Hecla No. 2," "Kanite A," "Masurite M. L. F.," "Titanite No. 7-P," and "Titanite No. 8-P," for which the detonator shall be of not less strength than the No. 7 (1½ grams charge of the same mixture).

3. That the explosive, if frozen, shall be thoroughly thawed in a safe and suitable manner before use.

4. That the quantity used for a shot does not exceed 1½ pounds (680 grams), properly tamped.

It must not be supposed that an explosive that has once passed the above-mentioned tests and has been published in lists of permissible explosives is thereafter to be considered a permissible explosive, regardless of its condition or the way in which it is used. Thus, for example, an explosive named in the permissible list, if kept in a moist place until it undergoes a change in character, is no longer to be considered a permissible explosive. If used in a frozen or half-frozen condition, it is not when so used a permissible explosive. If used in excess of the quantity specified (1½ pounds), it is not when so used a permissible explosive. And when the other conditions have been met, it is not a permissible explosive if fired with a detonator of less than the prescribed strength.

Moreover, even when all the prescribed conditions have been met no permissible explosive should necessarily be considered as permanently being a permissible explosive, but any permissible explosive when used under the prescribed conditions may properly continue to be considered a permissible explosive until notice of its withdrawal or removal from the list has been officially published, or until its name is omitted from a later list published by the Bureau of Mines.

Furthermore, the manufacturers of a permissible explosive may withdraw it at any time when introducing a new explosive of superior qualities. And after further experiments and conferences, the Bureau of Mines may find it advisable to adopt additional and more severe tests to which all permissible explosives may be subjected, in the hope that the lives of miners may be safeguarded better through the use of only those explosives that may pass the more severe tests.

PUBLICATIONS RELATING TO MINE ACCIDENTS AND TESTS OF EXPLOSIVES.

The following publications, except those having a price affixed, can be obtained free by applying to the Director of the Bureau of Mines, Washington, D. C. The priced publications can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

PUBLICATIONS OF THE BUREAU OF MINES.

MINERS' CIRCULAR 2. Permissible explosives tested prior to January 1, 1911, and precautions to be observed in their use, by Clarence Hall. 1911. 12 pp.

MINERS' CIRCULAR 3. Coal-dust explosions, by G. S. Rice. 1911. 22 pp.

MINERS' CIRCULAR 4. The use and care of mine-rescue breathing apparatus, by J. W. Paul. 1911. 24 pp.

MINERS' CIRCULAR 5. Electrical accidents in mines, their causes and prevention, by H. H. Clark, W D. Roberts, L. C. Ilsley, and H. F. Randolph. 1911. 10 pp. 3 pl.

PUBLICATIONS PREPARED BY THE TECHNOLOGIC BRANCH OF THE UNITED STATES GEOLOGICAL SURVEY.

BULLETIN 333. Coal-mine accidents: their causes and prevention; a preliminary statistical report, by Clarence Hall and W. O. Snelling, with an introduction by J. A. Holmes. 1907. 21 pp.

BULLETIN 369. Prevention of mine explosions, report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 1908. 11 pp. 5c.

BULLETIN 383. Notes on explosive mine gases and dusts, with special reference to explosions in the Monongah, Darr, and Naomi coal mines, by R. T. Chamberlain. 1909. 67 pp.

BULLETIN 423. A primer on explosives for coal miners, by C. E. Munroe and Clarence Hall. 1909. 61 pp.

BULLETIN 425. The explosibility of coal dust, by G. S. Rice, with chapters by J. C. W. Frazer, Axel Larsen, Frank Haas, and Carl Scholz. 1910. 180 pp. 14 pls.

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THE USES OF PEAT

FOR FUEL AND OTHER PURPOSES

BY

CHARLES A. DAVIS

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ILLUSTRATIONS.

THE USES OF PEAT FOR FUEL AND OTHER PURPOSES.

By Charles A. Davis.

INTRODUCTION.

SCOPE AND PURPOSE OF REPORT.

The Bureau of Mines is making a comprehensive investigation of the composition, heat value, and utility of the mineral fuels in the United States. In the course of its research the bureau is giving particular attention to methods of mining and utilizing fuels to the end that waste may be avoided and deposits of low-grade fuels now lying unmined may be made important assets of the Nation's mineral wealth. The investigation as a whole is a continuation of the testing and analyzing of fuels, as carried on by the United States Geological Survey, from the inception of the work in 1904 to the transfer thereof to the Bureau of Mines on July 1, 1910. In consequence of the transfer of authority this bulletin is published by the Bureau of Mines, though it was prepared under the direction of the Geological Survey.

The bulletin sets forth the results of an investigation that was undertaken to determine whether peat, a fuel widely used in some countries, could be made serviceable in the United States, where, though labor and economic conditions differ from those in the peat-using countries, there are opportunities for the introduction of a fuel selling at prices that should make the mining and shipment of peat to near-by markets profitable. In connection with the investigation of the possibilities of utilizing peat as fuel, attention was incidentally given the possible development of other uses with the view of increasing the value of a material that hitherto has not been generally considered an important natural resource of the United States.

DEFINITION OF PEAT.

The difficulties which have always been encountered in utilizing peat for fuel are due to the fact that in its natural state the material

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contains only about 10 per cent of combustible matter, the remaining 90 per cent, more or less, being water; this water is inherent because of the nature of the processes by which the peat is formed. The foregoing statement leads logically to the following definition:

Peat is partly decomposed and disintegrated vegetable matter that has accumulated in any place where the ordinary decay or chemical decomposition of such material has been more or less suspended, although the form and a considerable part of the structure of the plant organs are more or less destroyed.

Water makes an excellent medium for preserving the remains of dead plants, and hence also for aiding peat formation, since it excludes air and most of the organisms that are the chief agents that cause wood and other plant structures to rot and finally disappear. The water may contain certain poisonous organic chemical compounds that originated in the growing plants, as the result of their activities, or were formed as decomposition products. These compounds may act with water to prevent the growth of the organisms which cause decomposition, but that excess of water is the paramount factor in the preservation of the vegetable matter seems capable of demonstration.

The above statement is so generally true that peat deposits within the limits of the United States are practically always formed in situations where water for the greater part of the year either saturates or wholly covers the plant débris from which peat originates· In those places where vegetable material is saturated with water for only a part of the time and is subjected to periodical and prolonged drying out, true peat is not formed, but a more nearly complete decomposition takes place that results finally in the formation of humus; or, if the drying is continued long enough and other conditions are favorable, decomposition may go on until nothing is left of the plant material but the ash or mineral part.

GENERAL PROPERTIES OF PEAT.

According to its origin and the conditions under which it accumulates, peat may vary in color from brown to black. In texture it may vary from light, spongy matter that is porous, coarse, fibrous, or even woody, and easily falls to pieces when dry, to forms that are nearly or quite devoid of structure and when wet are as plastic as clay and when dry form dense, hard masses resembling lignite. In all cases, as noted above, peat is nearly or quite saturated with water, containing, under usual natural conditions, from 80 to 95 per cent.

When dry, peat is generally lighter in color than when freshly dug and will usually float if placed in water, although this is not always true of the dark-colored, plastic kinds that are high in ash and when thoroughly dry are as compact and nearly as hard as coal. Except

for such types, raw or untreated peat is easily crumbled to powder when handled, and makes bulky and unsubstantial fuel that does not bear transportation well. The name "muck" is commonly applied to black, impure peats of the more completely decomposed types.

BRIEF HISTORY OF THE USE OF PEAT AS A FUEL.

PRESENT INTEREST.

Within the past few years a marked depletion of the visible supplies of coal, the approaching exhaustion of the supply of wood available for fuel, and a constantly growing demand for fuel for industrial and domestic uses have led to a general advance in the prices of both coal and wood.

This condition has caused economic geologists, economists, and others to seek out and appraise new sources of fuel supply, and to contrive means of conserving and more perfectly utilizing the present supplies. The tendency toward more efficient utilization is shown in the development of interest in briquetting as a means of saving coal-mine waste and converting it into useful fuel, in the increasing use of internal-combustion engines as sources of power, and in the steady improvement of boiler furnaces and combustion chambers for burning solid fuels most economically. The same tendency is shown in the increasing use of compound steam engines and of devices for assuring complete combustion. Another manifestation of this tendency is the growing desire to investigate and utilize hitherto unconsidered kinds of fuel and to make use of sources of power other than fuel.

PRIMITIVE USE.

The earliest use of peat was for fuel, and dates back to the dawn of history. Latin authors of the time of the conquest of northern and western Europe by the Romans commented on the miserable condition of some of the people of those regions, who dug the soil from their marsh lands with their hands, and, after drying it, burned it to warm themselves and cook their food. In Ireland, of necessity, peat has been the only domestic fuel of the mass of the people from the traditional time when the forests of that country were finally cleared away.

Scarcely less ancient is the use of peat for fuel in other parts of northern Europe—Holland, Germany, Russia, and parts of France and Austria. The disappearance of the forests at a comparatively early period, while agriculture was the most important industry of these countries, led to the widespread use of peat fuel, especially by the poorer classes of people.

LATER USE.

Peat has long beeⁿ generally used in Europe as fuel for heating and other domestic uses, and more recently for power generation. Its production in compacted forms suitable for transportation and storage is growing constantly, so that at present every European country having any considerable area of peat deposits is increasing the output of peat fuel. In addition, Ireland and the countries of continental Europe are encouraging its use by direct appropriation of funds to aid new and promising methods of preparation, and are supporting experiment stations for investigating and perfecting new processes for utilizing this important natural resource.

In some parts of Canada, because of climatic conditions, the lack of any considerable deposits of coal, and the existence of generally distributed and extensive peat beds, more or less successful attempts have been made for 50 or more years to utilize peat as fuel. The matter has recently received new impetus there because of an industrial awakening and because of improvements made in gas producers and gas engines in Sweden, Germany, and the United States that permit satisfactory use of low-grade fuels. As a direct result of these factors, an experimental gas power station using peat is being established under governmental control and thoroughly equipped with the best European machinery.[a]

In the United States, for obvious reasons, peat had received but scant attention, except at the hands of a few widely scattered experimenters, until the winter of the year 1902–3, when the memorable long-continued strike of the miners in the anthracite regions of Pennsylvania brought a large section of the country to a realizing sense of its almost complete dependence on that group of men for its supply of fuel.

Since that time there has been an important, if unsuccessful, series of attempts to produce peat fuel on a commercial scale, and in the aggregate hundreds of thousands of dollars have been spent in equipping plants to manufacture it for the general market.

ADVANCES IN UTILIZATION.

After the development of the steam engine, and the great impetus which this gave to the commercial and manufacturing industries of all European nations, peat was used in constantly increasing amounts for the generation of power by those nations poorly supplied with

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a During a part of the season of 1910 the Mines Branch of the Canada Department of Mines operated on a commercial basis a demonstration peat-fuel plant. This was located at Alfred, Ontario, about 30 miles from Ottawa, and was equipped with Swedish machinery. Part of the 1,600 tons of air-dried machine peat produced by the plant was sold to those wishing to try the fuel, and part was used in the gas-producer plant established by the Government in Ottawa for testing peat, lignite, and similar fuel. These plants are fully described in Bull. No. 4, Can. Dept. of Mines, Mines Branch, 2d edition, 1910.

other fuels. Such use naturally led to material improvements in the ways of preparing peat for fuel, and to much experimenting aimed to increase the quality of the fuel produced and the rapidity of production. The period of experimentation covered more than half a century.

The experimental work has not been wholly confined to ways of utilizing peat as fuel, but has included efforts to discover numerous other uses to which the substance, or some part of it, might be adapted as raw material for some manufacture in regions where raw materials for the specified purpose were either not produced, were scarce, or were expensive.

Therefore, anyone desirous of undertaking the use of peat for any purpose will find it profitable carefully and critically to review the work that has been done in Europe, especially in Germany, Denmark, Norway, and Sweden, in order to get the benefit of the great amount of information that is stored in the literature relating to the subject. Not the least important sources of such knowledge are the records of failures which have occurred, because mistakes made and recorded need not be repeated.

In America much less need has arisen for the study of the possible uses of peat. In Canada, partly because of its small coal fields and cold climate, partly because of the greater abundance of peat, and doubtless, also, partly because of the fact that many of the settlers before coming to this country were accustomed to using peat as fuel and liked it, more persistent attempts have been made to develop a peat-fuel industry than in the United States. For 50 years or more some peat fuel has been produced in the Provinces of Ontario and Quebec and has found ready sale, although the manufacture seemingly has never been a great success commercially.

USE IN. THE UNITED STATES.

In the United States peat fuel, in the form of cut peat, was used in parts of New England almost continuously from the time of settlement until the use of coal became general. Peat bogs in various parts of Massachusetts and Rhode Island still show depressions that were made years ago by the removal of the peat for fuel, and in places remote from railroads some peat is probably still cut for local or individual use.

During the latter part of the Civil War, and in the years immediately following the war, considerable interest was shown in New York, Boston, and in some other parts of the United States, in the production of peat fuel on a large scale, and plants were established at various places in New York, New Jersey, Virginia, and New England to experiment with machinery and processes for peat manufacture. These plants seem usually to have had little financial backing,

however, and none of them, so far as known, ever reached the commercial stage of production. The one which probably came nearest that point was that of the Boston Peat Co. at East Lexington, Mass., where an excellent quality of peat and an efficient machine for macerating and forming it into bricks made a good product possible. The enterprise was carried along for some years, but was eventually discontinued.

In 1902-3 the strike of the anthracite coal miners already referred to created a fuel famine such as had never before been experienced in the United States, and revived the interest in the use of peat as fuel. Since that time many attempts have been made to produce fuel from peat on a profitable commercial scale, but for many reasons, some of which are considered hereafter, very little peat fuel of any sort has yet appeared in American markets. However, at least $1,000,000 in the aggregate has been spent in erecting plants and in experimenting with various processes of handling and preparing the substance. Because the closing of larger plants before they had reached a stage of demonstrated success was so general, more conservative developments have been planned for making a thorough trial of the material in favorably situated places under American conditions of production and fuel supply. Some of these are about to be started under much more favorable auspices than any of their predecessors.

It is evident from the foregoing that as yet no peat-fuel industry can be said to exist in the United States, although much experimental work has been done and great sums of money spent to establish one. In Europe the peat beds of various nations are sources of raw materials for industries of some magnitude, although their development is still in an experimental stage, as is pointed out in succeeding pages. In the United States, with few exceptions, the use of peat for other than fuel purposes has not yet been attempted, partly because of the great quantities of better materials available for the purposes, and partly because manufacturers are not sufficiently informed regarding the possibilities of different kinds of peat.

PEAT DEPOSITS IN THE UNITED STATES.

QUANTITY OF PEAT AVAILABLE.

So little exact information has been obtained in regard to the area and depth of the peat deposits in the United States that an accurate estimate of the quantity available is impossible. On the assumption that there are in the United States, exclusive of Alaska, 139,855 square miles of swamp lands,[a] it is estimated that 8 per cent of this area, or

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a S. Doc. 151, 60th Cong., 1st sess.

11,188 square miles, will have peat deposits of good quality. Assuming further that the average depth of the peat in this area is at least 9 feet, and that the average yield will be 200 tons of salable fuel per acre for each foot of depth, the total available fuel in these deposits will reach 12,888,500,000 tons; this quantity, if converted into machine-peat bricks and sold at $3 per ton, would have a value of $38,665,700,000—no mean resource, but one that would furnish heat and power for the entire country for many years.

DISTRIBUTION OF DEPOSITS.

Peat beds are not uniformly distributed over the country (see map, Pl. I), but lie chiefly in the region north of a somewhat irregular line extending westward from close to the southern boundary of New York nearly to the ninetieth meridian and thence northward to Canada. This region is supplemented by a narrow strip of land that extends along the Atlantic coast to Florida, includes the whole of that State, and reaches westward, probably across Texas, to the Mexican border. In the Pacific coast States there are some peat areas of workable size in California, and also in the valleys of some of the lakes and rivers of Oregon and Washington, but little is known of the extent and character of the deposits.

The reasons for this peculiar distribution of peat are not evident, but extended investigation will doubtless show it to be definitely correlated with certain geologic and climatic conditions which can not be discussed here.

It is an exceedingly interesting coincidence and a most important economic consideration, however, that the regions where peat is most abundant are relatively remote from the coal fields, the only exception being an overlapping of peat and coal in Michigan. In that State, however, as geologists are aware, the part of the coal field known to be commercially productive is not of large extent, but, so far as developed, is confined to small areas on the eastern and southern margins, the interior yielding but little coal. Aside from this area, the much-less marked overlapping of peat and coal in Illinois, and the slight coinciding of peat and lignites in the western border of the peat-bearing regions, there is a well-marked separation of the coal fields and the areas that contain peat. This is clearly shown on Plate I.

When one also notes that the more Northern States, in which fuel is most needed, and the parts of the Southern States where other kinds of fuel are not readily available, are rich in peat, it seems strange that a more careful examination into the possibilities of the peat resources of the country has not been made, because potentially they have large value and great possibilities.

RÉSUMÉ.

On the whole, then, it may be said that the use of peat for any purpose in the United States is small as compared with that in European countries. The peat beds are a great and neglected resource which, when properly and fully developed, will add to our national wealth no inconsiderable quantity of good fuel and of raw material for important arts and manufactures. The discussion will of necessity be devoted largely to the uses of peat in European countries and to the methods of securing marketable products in commercially paying quantities there. Only by carefully considering these can the mistakes and failures of the past be avoided and improvements of existing processes made.

It must also be considered that any mechanical devices and processes for making peat fuel and other products which are in successful operation abroad are those which have established themselves by demonstrating through a long period of years their value in competition with many others which have been eliminated because of failure to meet the demands put upon them by the requirements of actual commercial operations. These devices and processes are therefore all the more worthy of careful study by prospective investors in this country.

To summarize: The foundation of all successful development and growth of peat industries in the United States must be a thorough scientific study of the occurrence, nature, qualities, and peculiarities of peat itself and a careful and honest investigation of the status of these industries in the European countries in which they have reached self-supporting existence. To begin without these preliminary studies would be the height of folly.

COMPARATIVE COST OF PEAT AND COAL AS FUEL.

Comparing the cost of peat fuel with that of coal, the former could be produced with less danger and with a much less expensive equipment if it needed only to be dug, because it lies at or just below the surface of the ground. A readily marketable type of peat fuel, in the form of air-dried, slightly-compressed blocks, can probably be produced at an expense of from 75 cents to $1.25 or $1.50 per ton, and, with properly devised and properly arranged machinery, production on a large scale would considerably lower the higher price for peat of well-decomposed types.

On the basis of the comparisons of the heating values given in the following sections, and at the prices of production noted, clearly more heat units for the same investment of money could be obtained from peat than from coal, for 2 tons of peat could doubtless be bought for the same price as 1 ton of coal, and even the best coals

do not have twice the heating value, pound for pound, of good fuel peat. No peat fuel has yet been produced at such low cost in this country, however, and that the figures based upon European production can be made the basis of calculation for American conditions remains to be demonstrated. That the bulkiness of air-dried peat fuel will make the cost of transportation and of storage under cover relatively high must also be noted. The high cost of transportation will probably prevent the shipment of the product for any considerable distance from the place of origin except by water routes; the high cost of storage will easily adjust itself when consumers have an opportunity to learn the value of peat fuel.

Both transportation and storage are facilitated and objections of the sort mentioned are reduced to a minimum if the peat is compacted by thorough maceration, or pressed into small, dense, compact briquets by the use of powerful briquetting presses. As pointed out below, however, there are serious difficulties in the way of using the latter process, and until these have been removed and this method of preparation is a demonstrated commercial success no conclusions of value can be based upon it as a factor in this discussion.

RELATIVE VALUE OF PEAT FUEL.

In conclusion, peat fuel may be said to be especially useful for certain purposes for which wood was formerly in general use and for which coal has not yet been altogether successfully introduced, such as brick and other forms of ceramic firing and lime burning. It appears to reach its highest value, however, as a source of producer gas in properly constructed gas producers, and, as shown in the sections of this report devoted to the uses of peat (pp. 144–161), this is a very efficient way in which to use its energy.

The fact must be noted that no quantity of peat fuel of any type sufficient to prove its value has yet been produced in the United States; until this has been done, although the outlook and European experience warrant further investigation of its possible uses and value, no final conclusions as to the commercial value of American peat as compared with coal can be reached.

ORIGIN AND FORMATION OF PEAT.

NECESSARY CLIMATIC AND SURFACE CONDITIONS.

Peat is found in all parts of the earth where the conditions of moisture are favorable, but it is most uniformly present in regions where the rainfall is regular and abundant and the relative humidity of the air is constantly high. The first factor supplies the necessary water, and the second prevents excessive evaporation. As cool or cold air is much more readily saturated with water vapor than is warm air, the temperate and cold parts of the earth generally have more humid atmosphere than the warmer parts, and in this respect are favorable to peat formation.

The form of land surface is also an important factor in determining the relative frequency of occurrence of deposits of peat, especially in regions where rainfall is somewhat irregular, where the climate approaches dryness, or where hot, dry summers are somewhat frequent, as, for example, in the greater portion of the valley of the Mississippi and the southern part of the basin of the Great Lakes. In regions of this character the presence of numerous depressions in which water may collect and stand permanently at a nearly constant level, and of poorly drained valleys or plains, largely controls the quantity of peat that will be found, since these depressions furnish places where accumulations of vegetable matter may be kept from desiccation and complete decomposition.

From climatic causes the factors mentioned as favoring peat formation are most generally present in the cold and temperate regions of the earth. Especially is this true in the Northern Hemisphere, where there are land masses of great extent in which surface drainage has been profoundly affected by glacial ice so recently that there has not been time for it to become reestablished, and in consequence shallow, undrained basins and broad, flat valleys are numerous.

REGIONS IN NORTH AMERICA FAVORABLE FOR THE FORMATION OF PEAT.

Conditions such as have been mentioned are general in the eastern part of North America north of 40° north latitude, hence peat deposits are more numerous and more widely distributed in that part of the continent than to the southward and southwestward, whereas aridity is an unfavorable factor in the region west of the ninetieth meridian. In Canada, which lies practically wholly within the first-mentioned region, more than 35,000 square miles of land surface are covered by peat deposits; that part of the United States adjacent

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to the Canadian boundary and east of North Dakota is equally favorable in situation and has, in the aggregate, large areas of workable peat beds.

Southward of the fortieth parallel higher summer temperatures, longer summers, more frequent long droughts, and the prevalent drying winds, together with the more thorough drainage of the land surface, combine to bring about conditions adverse to peat formation; hence deposits are fewer and smaller than to the northward, or are entirely absent.

In this more southerly region the low relative humidity of the air for long periods during the summer months is doubtless an important factor in restricting the accumulation of peat. The drying winds and the heated air characteristic of summer in this part of the country constantly evaporate the water from the surface of the soil; the warmth of the soil decreases the viscosity of the soil water and permits it to drain away readily. Combined, these factors keep the surface of the ground in such a condition that very little peat can form upon it, despite the great abundance and luxuriance of plant growth induced by favorable climate and a long growing season. In the far north, on the other hand, where the growing season is short, even though other factors favor the development of peat, little will be formed because the vegetation of the region is too limited in amount to form accumulations of sufficient size. It is apparently true that peat may form to considerable thickness, even in high latitudes, in both the Northern and Southern Hemispheres wherever the climate is oceanic or the ground permanently frozen. No reports of the vegetable structure of these types of peat are available, however, and some of the observed accumulations may possibly represent a milder climate than that which now prevails in the regions under discussion.

The present state of our knowledge indicates that the deepest deposits of peat in North America, as well as those of greatest extent, are to be found from 100 to 150 miles on either side of the boundary between the eastern United States and Canada.

East of the Appalachian mountain system, however, the proximity of the Atlantic Ocean causes a considerably greater rainfall and much moister atmospheric conditions than are found west thereof. This is especially true of the Coastal Plain, a flat, imperfectly drained, relatively narrow strip of land that borders the ocean southward from New York, and, geologically speaking, has very recently come above sea level. There is evidently a combination of factors here which makes peat formation possible farther southward than is possible under the conditions on the western side of the mountains, viz: Poorly drained, flat land surface, heavy rainfall, and highly humid air.

From the foregoing statements it seems that two kinds of land surface are more suitable than others for the development of peat beds. These are basins and gently sloping or flat areas. In addition, a sufficient and regular rainfall and usually humid atmospheric conditions are essential in order that the basins may be permanently filled by water and the surfaces of the plains remain continually moist or wet.

It may be added also that wherever the precipitation is great enough, and the relative humidity of the air is high enough, or wherever, because of low air and soil temperatures, evaporation and run-off are slight, peat will form on any surface on which the necessary plant material can accumulate. Such conditions are not usual within the borders of the United States, although widespread in Alaska, and need not be discussed at this time.

CONDITIONS FAVORING THE GROWTH OF PLANTS.

Before going further into details relative to peat formation it is essential for a correct understanding of the way in which different kinds of peat may originate to consider briefly the principles of the relationship of plants to their environment and the conditions under which vegetation of different types can grow. An understanding of these makes possible a statement of the kinds of plants which may contribute to the peat of given regions and an absolute determination of certain of its characteristics. The matter also has an important practical bearing on questions relating to the use of peat for specific purposes.

At the outset it may be stated that green plants are the only types capable of independent existence and therefore the only ones that can make any considerable contributions to peat deposits. All of these, in order to grow, must have light, heat, air, water or moisture, and certain mineral and gaseous chemical compounds, which are dissolved in the water or intimately mixed with the air. The most important gases derived by plants from the air are carbon dioxide and oxygen. By the aid of light and heat the plants carry on in their green parts the very complicated chemical processes by which the raw food materials, consisting of carbon dioxide, oxygen and other gases, water, and mineral and other compounds, are converted into food and then into living cells, tissues, and organs.

The most durable parts of these structures after they have served their purpose in the economy of a plant remain more or less unchanged after its death, and under favorable conditions form peat. In the larger plants, like trees, some of these durable parts are in the form of wood, a hard, very complicated chemical substance; but the leaves of trees and the entire plant in many of the smaller and lower types of plants are made up of a softer, less dense, but very stable material called cellulose. It is from this material, which is a com-

pound of carbon, hydrogen, and oxygen, that a great part of peat substance originates.

Every plant requires for its existence and growth a certain quantity of each of the essential factors mentioned above, but each plant has its own particular needs, and differs from all others in the least or minimum quantity of some or all of these factors which it must have in order to maintain itself and in the tolerance which it shows to the presence of a quantity in excess of its needs.

Thus some plants require much light; others can flourish in or must have the shade; some grow well in dry places; others must have quantities of water if they are to live at all. On the other hand, an excess of light, heat, water, or of dissolved minerals or other soluble matter is detrimental, and may completely stop growth quite. as certainly as deprivation. These matters, however, need not be discussed at length in this place, as they are fully illustrated in the succeeding paragraphs.

PLANT DEPOSITS IN DEPRESSIONS FILLED WITH WATER.

Water-filled basins, lakes, and ponds are first considered because they present in a way the simplest conditions of growth for plants, and in them the combinations of the essential factors of plant growth as related to the formation of peat are most easily understood.

AQUATIC PLANTS.

Plants of several great groups or classes habitually grow wholly or partly submerged in water. The algæ, certain mosses, and a few other less frequent kinds of spore-bearing plants, which are the lowest types of vegetation, normally grow entirely beneath the surface of the water. They either float without attachment just below the surface or deeper, or are attached to the bottom or to other fixed or floating forms in shoal water.

The algæ are purely aquatic plants represented by great numbers of species and often by enormous numbers of individuals in a given locality. Fresh-water algæ, with which this discussion is chiefly concerned, are plants of simplest structure and of small, often microscopic, size. In them the vegetative body is without differentiation into roots, stem, and leaves, as in most seed plants, but consists of one or more cells which perform the essential functions of all of these organs. The most common and easily recognized fresh-water algæ are the bright green "pond scums" so abundant in still water during the spring and summer. Since these plants float about in the water their remains may be found at any depth from the surface to the bottom.

Of the great groups of plants higher than the algæ, none of importance is made up exclusively of aquatic plants; in fact, none has more than a relatively small number of representatives which grow

wholly in the water. Among these higher types may be mentioned the mosses, the liverworts, a few of the fern allies, and the flowering or seed plants. The mosses and liverworts are small in size, simple in structure, and generally rootless, but under favorable circumstances they sometimes flourish in vast numbers, even to the exclusion of other types, and they may then form extensive beds of peat by their growth and partial decay.

SEED PLANTS.

The seed plants, or flowering plants as they are often called, are more differentiated in structure than the types already considered and are correspondingly more rigid in their requirements than the algæ and mosses. Among other well-marked distinctions is their very general dependence upon the soil for water and mineral matter. These they take up by subterranean organs, specially adapted to this purpose and called roots, with which they are usually provided.

Aside from the general necessity of attaching themselves to the soil, the seed plants also differ from the lower types by having their cells organized into tissues, and these are further differentiated into organs with special functions. This more complicated organism implies in turn certain exacting requirements as to favorable conditions for growth and development, and the various kinds of tissues, some of which possess great strength, enable the seed plants to reach large size; hence they usually contribute more abundantly and more noticeably than the smaller plants to any accumulations of vegetable matter which may be formed where they can grow. In general, except under the unusual conditions given below, they constitute the chief peat-forming types, but they are land-loving forms, and only a relatively small proportion of the entire group is able to live in the water.

AQUATIC SEED PLANTS.

The aquatic seed plants may at once be classed in two chief groups: First, the kinds that are truly aquatic and grow habitually under water, sending only their flowers to the surface, and, second, those with a part or all of their vegetative organs, leaves, and stems, as well as flowers, reaching the surface and floating upon it, or rising into the air above it.

As most of these plants have roots which penetrate the soil at the bottom, each species is restricted in the depth of water in which it can grow by the depth to which sufficient light and heat can penetrate to permit the development of young plants from seeds and other propagating organs. The precise maximum depth at which this occurs apparently varies with the clearness and temperature of the water of individual lakes, but it rarely exceeds 15 to 18 feet, and very few species are able to start growth, or to persist after starting in water of such depth.

EFFECT OF SUNLIGHT AND DEPTH OF WATER.

Toward shore from the maximum depth at which seed plants grow the number of individuals and species increases; each species, however, is limited by the depth of water in which it can thrive. Hence where the slope and the character of the bottom are constant enough to give uniform conditions at given depths entirely around the basin the growing plants will obviously distribute themselves around the deep water in definite bands or zones whose width will depend upon the angle of slope of the bottom.

Those species growing in water of the greatest depth are wholly submerged, and are characterized principally by slender, flexible stems, and long thin leaves. In somewhat shallower water, types like the water lilies will grow. Such types have leaves that rise to the surface of the water and float.

Plants of the last-mentioned kinds intercept the light falling upon their leaves, and when abundant so darken the water below that they keep submerged species from successfully competing, or suppress them entirely, and thus develop a zone distinct from that in deeper water. Plants of the pond-lily type thrive in moderately shallow water, except where they do not receive full sunlight. They are, therefore, restricted on the shoreward side to a depth of water in which grow those species whose stems and leaves reach above the water's surface and expand in the air above, intercepting the light and casting shadows. Plants of this sort are well represented by the bulrushes, some of the water-loving sedges and grasses, and other types, like the pickerel weed, that frequently grow in dense masses in shallow water along the margins of lakes and slow streams, especially where the bottom soil is good.

The plants of this type most tolerant of water and poor soil conditions are the lake bulrushes, *Scirpus validus* Vahl., and closely related species, which may spring up and thrive in water somewhat more than 5 feet deep. Species with floating leaves may obviously be overshadowed at this depth.

Shoreward from this maximum depth of slightly more than 5 feet, the light may be intercepted above the surface by plants that increase in numbers of species and individuals as the depth of water decreases. These plants crowd into the shallows and frequently take complete possession of the bottom by means of strong, tough, much-branched, underground stems and deeply penetrating fibrous roots, which by degrees form a firm dense turf by constantly increasing accretions of new growth. Periods of drought and consequent low water doubtless aid the advance of plants of this kind. Such periods afford conditions that are favorable to development of these plants and hasten the time when the turf may become so strong and buoyant as to build out from the firmer part of the bottom and form a floating marginal

shelf or mat. This mat, rising and falling with the water level, is gradually extended by the constantly advancing plants until the open water in the basin is entirely filled and covered.

DEPOSITION OF PLANT TISSUES.

In the orderly sequence of plant groups above detailed each member of all of the associations adds to the bottom from which it has grown, at least a part of the tissues that it has built by its life processes. The more highly organized plants in sinking carry the numerous attached or entangled algæ and other organisms and fine sediments, and by so much increase the total deposit.

By this constant accretion of dead tissues the bottom on which any group of plants has established itself is built up, shoaling the water, and opportunity is given for shoreward types to occupy the new territory thus made available to them. They may then push lakeward or crowd out entirely the deep-water species that have so far held the ground and made it more habitable.

Each plant zone makes its advance in order from the older to the new position. But as the shoreward zones are more densely populated than those farther lakeward, and as the plants forming their associations are more abundantly supplied with firm, tough tissues and other vegetative structures, the upbuilding goes on more rapidly in shallow water. Because of these facts a tendency develops for the deep-water zones to become narrow as the slope of the lakeward face of the deposit gradually grows steeper. On the other hand, the tendency of deep-water zones to become narrow is checked to some extent by the spreading out of the accumulations of the shoal-water zones. Winds and currents act to spread these accumulations after they have been loosened by storm waves. In consequence the deposits are finally built up near enough to the surface to be covered and protected by the turf-forming plants. These are quick to occupy any areas of the bottom which approach the surface of the water, and prevent further disturbance of the surface of the deposit by holding the material firmly in place, so that from the time they gain roothold the growth of the deposit goes on steadily until its surface is raised above the level of the water.

Once started under natural conditions, this process goes on with only such interruptions as are due to fluctuations of the water level caused by variations in rainfall and evaporation, or by disturbances of the drainage of the basin, the lake becomes slowly but continually shallower and smaller until it entirely disappears and a marsh replaces it, and the basin is completely closed by the peaty remains of the plants that have grown in the water or slightly above its surface.

Therefore, the peat which accumulates in lakes, ponds, or other water-filled basins is built up at first by aquatic plants, including

minute algæ, that form a deposit from the bottom and around the sides of the depression, extending out from the shore to a depth of about 15 feet. The material thus formed is added to in many cases and in varying quantity by drift material blown in from the shores by the winds or carried in suspension by inflowing streams.

ZONES OF AQUATIC VEGETATION.

In basins where the conditions of plant growth are favorable and certain kinds of plants become established, the aquatic vegetation arranges itself in well-defined zones more or less concentric around the deepest part of the lake. Each zone is characterized by some dominant group of plants, which in the northern United States are, broadly speaking, always as follows, beginning with the zone in the deepest water and progressing shoreward: (1) the pond weeds, *Potamogeton;* (2) the white and yellow pond lilies, *Castalia* and *Nymphaea;* (3) the lake bulrushes, *Scirpus;* (4) the amphibious sedges, *Carex, Eleocharis,* etc., especially the turf-forming slender sedge, *Carex filiformis* L., or species of similar habits. In the open water of any depth the unattached algæ and certain rootless seed plants may grow, and these often are abundant enough to constitute a considerable element in the formation of peat; very rarely certain mosses, including *Sphagnum,* are found growing in this way.

In the southern border of that part of the country where lakes and ponds are numerous and southward thereof, a peculiar semiaquatic plant, the swamp loosestrife *Decodon verticillatus* (L.) Ell., is usually found bordering the open water in a broad, dense zone, excluding all other species. This plant establishes itself by means of long, slender, arching branches, the tips of which develop buds and roots when they touch water, and thus form new plants from 1 to 3 feet away from the original station.

By the stem from which it grew the new plant is held in place for a year or more, during which time it may be able to secure firm roothold on the bottom below. In this way the open water of the basin is closed in, as fast as the peat is built up, by aquatic plants near enough to the surface for the roots of the *Decodon* to reach bottom.

The species forms dense woody stools, the tops of which rise several inches or even a foot above the water level. On these many kinds of plants find growing places and close in the open spaces between the stools until there is formed a firm structure on which shrubs and trees may at once establish themselves without the intervening period of the dominance of sedges.

Plants of each of these zones contribute to the vegetable accumulations, and as the mass of débris is slowly spread into the deeper parts of the basin, if these exceed the depth of 15 feet and the bottom is raised sufficiently so that the plants may grow upon it, they move

into the newly made territory in the same order in which they have occupied the old.

It should be noted, however, that any or all of the zones of aquatic plants may, without perceptible cause, be absent from a part or the whole of lakes in which they might be expected to occur, and that few ponds in a given region have exactly the same species or the same abundance of individuals of the kinds present. It is nevertheless true that where the various zones of plants are at all completely represented, the order of occurrence given above is invariable, unless the bottom of the basin is broken by shallows or by deep holes.

VEGETATION OF WET SEDGE MAT.

With respect to the vegetation of the wet, poorly drained soils formed by the advance of plants upon a body of water, the conditions which exist in those places where a floating mat or marginal platform of turf has been formed by the sedges do not materially change until the mat is given stability and is fixed with regard to the normal water level by grounding or by becoming so thick that it no longer rises and falls with temporary changes of the water level. The mat is always sufficiently buoyant to prevent its sinking much below water level, and even when very old and sufficiently firm to support large trees it is rarely more than 4 or 5 feet in thickness. Where thickest and oldest it is always sharply differentiated in its structure from the deposit formed by the remains of the true aquatic plants below it, so that its vertical limits may be exactly determined.

In its younger stages of formation the mat is thin, being often less than 18 inches thick, and may have several feet of clear water below it. It also lacks the firmness found in later stages.

Upon the surface of the sedge-formed turf, after it has ceased to rise and fall with the changes in height of the water, other plants than the sedges make their appearance, and these also arrange themselves in zones, in accordance with their requirements for or tolerance of water about their roots. Most land plants require that their roots shall receive, by contact in the soil, the air which they need, and an excess of water, in so far as it excludes air, is detrimental. Thus, unless plants have special adaptations for supplying air to their roots, they are soon drowned out of saturated or very wet soils. This need of air for their roots is a most important factor in limiting the distribution of those terrestrial plants which are concerned in the formation of peat, and one which becomes operative as soon as a deposit reaches the surface of the water, or, in the case of the sedge mat, as soon as there is a portion of it exposed to the air.

HERBS AND SHRUBS.

Among the very first plants to appear upon such a surface are certain herbs, which may grow even on drift materials brought together

by winds and waves on the mat while it is still floating, or on slight ridges formed by ice shove. The fact that these plants grow only on such elevations above the level of the water is a plain indication that they can not endure as much water as the semiaquatic sedges. It is by no means uncommon to find many of these first invaders of the sedge mat growing as epiphytes attached to the stools formed by groups of the stems of sedges, or attached to the stems of the larger types of sedges some inches above the water, their roots growing into the dead leaves and other débris that has found lodgment in such places.

Such pioneer herbs, principally annuals and therefore able to take advantage of a single favorable season, are quickly followed out on to the drier and firmer parts of the mat by certain shrubs of the heath and willow families.

Over much of the region where this kind of peat deposit occurs the most common of the pioneer heaths are the leather leaf, or Cassandra, *Chamaedaphne calyculata* (L.) Mœnch, and the Andromeda, *Andromeda polifolia* L.; other species of shrubs occur, but they are less general in their distribution or later in their appearance. The species mentioned form long, horizontal, underground stems, from which arise at intervals erect leafy branches; in this way the plants spread rapidly when once established and make a dense growth, which before very long shades and destroys the sedges.

SPHAGNUM, OR PEAT MOSS.

Sooner or later after the conditions enumerated have become established *Sphagnum*, the so-called "peat moss" appears, generally following the shrubs—more rarely, with them. *Sphagnum* is the large, grayish-green, whitish and pinkish moss, so widely distributed in swamps and bogs,[a] especially in the northern part of the United States and in Canada. The plants grow continually at the top, dying below, and in favorable places individual plants may be found that have made a growth of more than a foot in length before the lower part of the stem is lost in the disintegrated mass below. As the individual plants approach the limits to which they can grow above the water level, growth becomes very slow, and they appear stunted and may finally dry up completely and be succeeded by other types.

On the other hand, the moss grows rapidly when once established and quickly raises the surface of the peat by pushing up among the branches of the shrubs with which it grows. As shown above, it is limited in its upward growth by the height to which water will rise from the general level through the spongy mass below the living tips, and this height, except in very moist climates, rarely exceeds a few feet. In Michigan the distance is seldom more than 3 feet and is often

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[a] At least one of the species of *Sphagnum* occurring in the northern United States is aquatic and in one locality has been found growing as a floating plant in the open water of a small lake.

less, but if the water level rises with the upgrowth of the peat, the moss débris may become many feet thick.

CONIFEROUS TREES.

Following the shrubs and *Sphagnum* appear a variety of coniferous trees, among which are the tamarack, *Larix laricina* (Du Roi) Koch; the black or swamp spruce, *Picea Mariana* (Mill.) BSP.; the arbor vitae, *Thuja occidentalis* L., and, in certain places, the pines, especially the scrub pines, *Pinus Banksiana* Lamb. and *Pinus rigida* Mill.; and less often the white pine, *Pinus Strobus* L. These trees are replaced by others in the Coastal Plain region, but for each climatic district there are usually tree species that establish themselves after the sphagnum-shrub association has raised the general surface of the peat above water level. They appear first as scattered individuals and subsequently form a zone near the shore. From this vantage ground, as the basin is more completely filled or the water level is lowered, they eventually cover the entire area, and as they grow taller than the other plants and intercept a large amount of light they soon destroy such plants as require the full sunlight for development.

DECIDUOUS TREES.

Following the coniferous species, certain broad-leaved deciduous trees secure foothold and in their turn displace the conifers by over-shadowing the latter during youth. The deciduous trees form the end of the cycle. By the time they have become dominant the surface of the peat has reached such a height above the level of the ground water that disintegration and decomposition go on each year at about the same rate as accumulation from additions to the deposit made at the surface by the trees, and thus the conditions of the soil are kept stable.

At any time, however, if there is a marked and sufficiently long elevation of the water level the trees will be destroyed, and those lower-growing types of plants that are adapted to the new conditions will reappear. These will begin again the work of peat forming, and the series of stages above described will be passed through until once more the trees are established.

DEPTHS AT WHICH DIFFERENT KINDS OF PEAT ARE FORMED.

The many minor variations of the way in which lakes and ponds are filled are of scientific interest and importance. It is, however, sufficient to note here that where the depth of water is less than 10 feet the plant species usually restricted to water of greater depth may be entirely absent and a whole lake may have only a single type of plants conspicuously present or only such zones as are found in shallow

water.   Or, even in shallow basins, the water may be so dark colored from the presence of suspended and dissolved organic matter that all but floating aquatic plants are absent.   Under such conditions the basins fill from the margins chiefly and from material washed and blown into them, and the actual formation of peat makes little progress.

Lakes in peaty swamps, such as those in the southern part of the Coastal Plain, have water of this character and are conspicuous for their lack of aquatic vegetation and for the small amount of peat that they contain; those in the same latitude with clear water have an abundance of plant life and are often partly filled with peat.   The writer attributes the absence of plants in lakes with dark water to lack of light rather than to other factors, because the shores and shallow waters of such lakes are often crowded with the same kinds of plants that live in similar habitats in clear lakes.   The absence of aquatic vegetation has also been noted in lakes of brown water in other regions than that mentioned, and there also the same close connection between water coloration and plant growth seems to exist.

SUMMARY AND CONCLUSIONS REGARDING THE PEAT OF WATER-FILLED DEPRESSIONS.

In general, it may be said that ponds and lakes are often filled with peat nearly to water level by the accumulation of the remains of aquatic plants, which vary definitely in type according to the depth of the water; that from near the water's surface to slightly above it sedges are the important contributors to the peat; and that because of slow elevation of the water level from any cause or because of slight sinking of the turf which they form, their remains may constitute several feet of the top of the peat deposit.

After the surface of a peat accumulation is raised so far above the water that it no longer is overflowed, herbs of many kinds may replace the sedges; when it is permanently from 6 inches to a foot above the water level, shrubs and *Sphagnum* usually take possession.   When the accumulation has reached a depth of a few inches more, trees become the dominant plants.   With their appearance the peat practically ceases to increase in depth unless there is an elevation of the water level.   The chief points to be noted are: (1) That peat which has been formed in basins is largely built up by aquatic plants; (2) that the vertical range of the growth of such plants is from the surface to a depth rarely exceeding 15 feet, at which depth the formation of peat by plants attached to the bottom practically ceases.   Peat of greater depth than this below a water level that has been constant since the filling began is generally made up of the remains of floating

organisms mixed with fine organic and mineral silt and other mineral matter brought in by streams, etc.

These facts have a definite bearing on commercial exploitation in that they point out the limits of depth at which certain kinds of peat may be expected to occur in filled basins. Since water retards decomposition and carbonization, the peat found below the water level in basins will be only slightly decomposed although usually thoroughly disintegrated.

PEAT FORMATION ON POORLY DRAINED, FLAT-LAND SURFACES.

DRAINAGE CONDITIONS.

A consideration of the accumulation of peat on moist, or wet, poorly drained land surfaces, whether these are without inclination or sloping, will involve the same laws of plant growth as in the preceding discussion. Peat will form wherever plants will grow, provided that the organic matter is kept constantly saturated with water.

Included as flat areas in this discussion are plains, plateaus, lake and stream terraces, valley floors, deltas, flood plains, and other types of land surface, which are too young, too flat, or too frequently covered by water to be well drained, and on which, therefore, the water level for the greater part of the time is at or near the surface, the soil below being saturated. On such surfaces the conditions of peat accumulation are manifestly different from those already discussed in that the level of the water is below the surface, or, at most, only slightly above it. This at once eliminates all of the kinds of plants enumerated above except those of the very shallow water or the wet shore.

VEGETATION AND VEGETABLE DEPOSITS.

The plant types most commonly found in the kind of places under consideration are grasslike in form. They have long, slender leaves and weak aërial stems that die down to the ground or perish wholly at the end of the growing season. Many of them, however, have horizontal underground stems that persist through several years; from these grow great numbers of long, threadlike, much-branched roots that penetrate the soil for considerable distances. Sedges, grasses, rushes, bulrushes, and cat-tail flags illustrate this type of vegetation. The whole group may be called turf-forming plants, since the underground stems of individuals of many of the species spread out horizontally in all directions and soon become interwoven and bound together by the numerous roots to form a compact, tough mat of vegetable matter. To this the growth of each succeeding year adds material, and after a time it may be stripped from the underlying soil without breaking.

The aërial parts of the plants, falling to the ground at the end of the growing season first form a covering for, and later, by the processes of decay, are added to the top layers of the soil and become incorporated in the turf.

If a poorly drained, wet area of mineral soil is freshly exposed to the ordinary influences of the climate of the region in which it lies, the usual results are that the seeds of many kinds of plants fall upon it, through various agencies of seed dispersal; that some of these seeds germinate; and that some of the seedlings reach maturity. Plants of such origin vary largely in their power to adapt themselves to the conditions of growth that surround them in the new environment; some will persist and others utterly fail to establish themselves.

Those that establish themselves, however, almost immediately begin to modify the soil conditions (1) by hindering evaporation from the ground surface and (2) by checking the run-off of the surface waters, which are thus held back in their passage over the area, and consequently rise to a higher level than before the plants appeared. The increased wetness is unfavorable to many kinds of plants which may appear on such land, and they disappear from the area more or less promptly, according to their tolerance to excess of water in the soil.

After a time, which varies according to the existing conditions in a given locality, but especially according to the level permanently reached by the ground water at the end of any period of plant occupation, the area will be covered by a definite group of plants, which even casual examination will show to be made up of large numbers of individuals of a much smaller number of species. Under the supposed conditions, peat formation begins soon after the establishment of plant associations that permanently cover the ground, provided that the water level remains high enough in the ground to prevent the complete decomposition and disintegration of the débris resulting from the growth and death of the plants constituting the associations.

The commencement of peat formation introduces still other complications into the conditions that vegatation must meet in order to maintain itself, because the structure, texture, and composition of the soil are changed, its wetness increased, and certain products of growth and decay that are injurious or even poisonous to some kinds of plants are introduced into it. The soil water is increased because the decaying vegetable matter and the peat act like a sponge—holding the water absorbed by them. They also clog up small drainage channels and thus hinder the run-off of meteoric water falling on the surface. The substratum in which the plants must grow becomes fibrous; it also becomes poor in mineral matter and in available necessary gases and, sometimes, rich in toxic matter.

After a time, however, the period of adjustment is completed and a state of stability is reached; then the plants fitted to thrive in or endure the environment offered are able to establish permanent associations. Following the state of stability, if other factors of plant growth remain unchanged, the development of the peat may go on rapidly; this in turn may check the outflow of water from the area. Hence, as the deposit is built up, the water level may rise and maintain a nearly constant relation to the surface. The invasion of new kinds of plants is thus prevented and the peat may accumulate to the depth of many feet, as the result of the growth of plants of the same type, associated much as they were in the early stages of peat formation.

RELATIVE IMPORTANCE OF DIFFERENT TYPES OF PLANTS.

Although the herbaceous types of plants assumed to take possession of the wet area in the foregoing discussion are those which are most frequently found in such places, it is evident that they are not the only ones which may become dominant. If the average water level on the area were from the first sufficiently far below the surface, woody plants (shrubs and trees) instead of the kinds described would form the permanent plant covering. Such a plant association would imply better aëration of the soil than would herbs. It would also involve more complete decomposition and carbonization of the finer vegetable structures that reached the ground, and hence the accumulation of a darker colored and less fibrous peat. This, however, would usually contain considerable quantities of partly decomposed wood.

The formation of peat by woody plants seems to be more frequent in southern than in northern parts of the United States. This condition may be attributed to the greater rapidity with which the water level is lowered in the warmer climate of the south by evaporation and run-off as well as to differences in the texture of the original mineral soils, owing to differences in origin.

It is also possible, where the air is very humid, as in places near sea level and close to the margin of the ocean, that some of the lower types of plants, such as mosses, will become the most important members of the group of plants growing on the area, and may form peat beds of considerable depth and extent. The best illustrations of this type of peat bog occur in the extreme northeastern part of the region under consideration, in eastern Maine, where beds of peat built up to more than 20 feet in thickness, chiefly by *Sphagnum*, are not uncommon.

SIGNIFICANCE OF THE TYPES OF PEAT STRUCTURE.

When the growth of the peat is not accompanied with a corresponding rise of water level, there will clearly be a change in the plant associations and in the types of plants growing on the surface as this is built up above water level and the drainage improves. The record of such changes in the character of the vegetation will be preserved in the peat beds. These will be irregular in structure, and, if mature enough, the upper layers will be more thoroughly decomposed than any of the others, since they will be most completely aërated.

Such beds will normally increase in depth until the surface gets so far above the water level that wasting goes on as fast as deposition; then, unless some change in the supply of water occurs, no more peat will be formed. If, however, for any reason, such as increased rainfall or obstruction of the drainage by fallen timber, the ground-water level rises again, a new period of peat accumulation begins, and the structure of the peat deposited is changed according to the type of plants that the new conditions establish. Hence, beds of peat built up under such conditions show heterogeneous structure in which the changes in the water level are recorded in variations in the kind as well as in the degree of preservation of the vegetable matter laid down and preserved.

If it be assumed that the remains of trees and other woody plants indicate the lowest level of the soil water possible for peat formation, a number of woody layers in a given bed of peat indicates an equal number of approaches to this maximum unfavorable stage. Also, beds of moss and shrub remains usually indicate less favorable conditions than do beds of grasslike plants.

PEAT FORMATION ON SUBSIDING COASTAL AREAS.

It may be considered demonstrated from the foregoing that the remains of plants, preserved as they grew but below that level of the water at which the species can live and grow, indicate with certainty either that the water level has risen since they were alive or that the land surface below the deposit has sunk.

If the given area is near the continental margin, and the ground-water level is affected by the sea water, significant changes of level may often be attributed to movements of the ocean bottom and the adjacent land. The evidences of the operation of such a cause are very clear when remains of plants, to which even a small amount of salt water is known to be fatal, are found submerged below the sea. In many localities stumps and roots of trees, associated with deposits of peat built up by fresh-water plants, are now buried below sea level by later salt-water deposits, and some such remains are even found in the seaward side of the present ocean beach.

With the assumption that the existence of such conditions shows that at least portions of the coastal plain have actually sunk, the effects of such subsidence on the formation of peat may be considered. The first effects of the subsidence will be to modify the drainage of the region in which it is taking place by checking the outflow of water from the mouths of the valleys that reach to or below sea level. This stoppage will increase the wetness of the wet parts of the region of subsidence by so much as the water is held back upon them by the inflowing tidal waters. After a time a reaction of this increase of water in the soil upon the vegetation should be evident and should be recorded in contemporary peat beds. If the subsidence is rapid enough to cause the water level to rise faster than peat is formed, the character of the vegetation preserved in the peat should vary to show this condition; more aquatic forms should appear in the upper than in the lower layers. When the rate of growth more nearly equals that of subsidence, the resulting peat should be more uniform in structure; the principal apparent changes should be those marking the transition from fresh to salt water conditions when the tide finally overflows the area of peat deposition. However, no sharp line of division may exist, since under the assumed conditions there may be a considerable deposit of the remains of plants that tolerate brackish water. The more durable parts of these are very similar in structure and appearance to those of species growing only in fresh water.

If the rate of the subsidence exactly equals that of the growth of the peat, the same kinds of plants should theoretically continue indefinitely to form the bulk of the peat. Actually, however, because of erosion and the effects of storms, after the surface of the peat has been brought near the high-tide level, salt water is likely to cover it with increasing frequency during storms and spring tides, so that salt-marsh conditions gradually develop.

SALT-MARSH PEAT.

Salt-marsh peat deposits and those made in areas overflowed by salt water are generally at once distinguishable from those formed under usual fresh-water conditions. The former contain a large amount of finely divided mineral matter, usually sufficient to give them a noticeably grayish color when dry, and gritty feel when crushed between the teeth. On parts of the ocean shores exposed to strong wave and current action, the mineral matter is gathered up by the sea water from the shallows and settles on the areas of overflow, wherever the motion of the water is arrested.

RELATION OF FORMATION TO TIDAL LEVEL.

It may be said at this point that but little vegetable matter accumulates between the average low and high tide marks. This is due partly to the constant motion of the water and partly to the very sparse vegetation between the zone near low water where the common eel grass lives, and that of the surface of the salt marshes on which salt water stands only during the high tides. If peat occurs between these, it must have been formed by plants growing at or above the usual level of the tides, and must indicate subsidence to the extent of its thickness, or more, if the structure of the peat is such as to indicate fresh-water origin. If then the section of a bed of peat in a salt marsh shows that it has been built up to a thickness of several feet by plants such as are now found on the surface of the marsh at or slightly above the average high-tide level, the formation of the material has evidently gone on at that level, and on a substratum that was subsiding at the same rate as the upbuilding which gave conditions of plant growth that were the same throughout the whole period. If plant débris had accumulated faster than the bottom subsided, fresh-water plants would have supplanted the salt-marsh flora as soon as the surface strata had been built above the tide; if the bottom had sunk faster than the rate of upbuilding, plant remains would have given place to mud and silt.

By a similar consideration of the possible conditions surrounding the growth of plants at and near the high-tide level, it will be possible to obtain records of irregular periods of subsidence, and of slight oscillations of the plain forming the continental margin. These periods affect the quantity and quality of the peat formations in the region in proportion to the length of time which they continue. In some observed cases where salt marshes have protecting beaches between them and the sea, the destruction of the barrier may permit freer inflow of the tides and suddenly modify the peat-forming flora. Such effects, however, would be small in character and extent in relation to the whole coast and would not cover very wide areas nor considerable depths.

ECONOMIC VALUE OF SALT-MARSH PEAT.

Economic importance attaches to the invasion of salt waters, heavily laden with silty mineral matter, into areas in which ordinary peat has been formed. The peat that is developed after the salt-marsh plants appear is usually too high in ash to make satisfactory fuel. In general the beds of peat resulting from salt-marsh conditions, as outlined above, can have only local use and will furnish very low-grade fuel. They may probably be used as sources of power gas,

although even for such use trouble is likely to occur from the high ash content and the fusion of the mineral matter into slag and clinker in the gas producers.

PEAT FORMATION ABOVE FILLED DEPRESSIONS.

The plains formed by bogs filling depressions are often so wet that peat formation continues above the original level of the water in the depression. In such places the plant associations establish themselves in accordance with the laws which have already been discussed. The ones best adapted to the existing environment invade and hold the area as long as conditions remain suitable for them, and peat formation goes on until the water no longer rises sufficiently to prevent desiccation and oxidation of the plant débris as it accumulates.

The effects of prolonged drought upon peat formation in such places are the same as in other situations, and are such as follow the lowering of the water level and the penetration of the air into the accumulated vegetable matter. These two factors permit the entrance of organisms producing decay which, with the air, disintegrate and blacken, or carbonize, peat, reduce its bulk and lower its surface. This is particularly true around the margins of the swamps where the peat is already thin and the drying most severe; in such places there is often a well-defined depression resulting from the alternating rise and fall of the water level due to seasonal and periodic fluctuations of rainfall and evaporation.

In any peat deposit, blackened, thoroughly decomposed layers, either with or without woody matter, may be taken to indicate a period of low-water level or drought. If such layers recur at various levels they show that the conditions have been repeated from time to time in the history of the deposit.

On the other hand, periods of unusual precipitation and moisture may be recorded in peat beds by poorly decomposed and fibrous strata of plant remains, or, if long continued so that the water permanently rises, by an entire change in the kind of material present in the contemporaneous strata.

LATERAL GROWTH OF PEAT BEDS.

Incidental to the growth of peat, there may be so much interference with the drainage that swamp conditions may spread laterally and cover with peat a part or all of the plain surrounding the depression, or they may even push up well-defined slopes where climatic conditions are especially favorable for the formation of peat. Discussing the possibilities still further, it may be said that on very broad, flat plains or on gentle slopes, in regions of heavy rainfall and high atmospheric humidity, the lateral spread of the peat, as a swamp increases in diameter, will at length react on the vegetation of the

most poorly drained part because in that place the water level will rise in proportion as the water fails to drain away. This rise in water level will make conditions less favorable for plant growth, and peat will not accumulate as fast as in the surrounding areas, and thus a pond may be formed. Later, since the accumulated water in such places is usually very dark colored and only slightly transparent, thus preventing the growth of aquatic plants below its surface, the area covered by water will increase as the peat is built up around the margin.

Such ponds should not be confused with the many small, deep tarns in the middle of small swamps and peat bogs, as these are manifestly the open water in the unfilled part of a depression. In the former type the water in the lake will be no deeper than the peat surrounding it, if it is as deep, whereas in the latter it may be much deeper.

RATE OF PEAT FORMATION.

No data of value relative to the rate at which peat is formed in the United States have been obtained, but there are indications that the rate varies greatly even in the same locality.

GENERAL CONCLUSIONS RELATIVE TO THE FORMATION OF PEAT.

Many factors may operate to change the character of the dominant types of vegetation from which peat beds may originate. These factors may also affect the resulting peat, under the varying conditions of climate existing over the great areas of the United States in which peat may be found. The resulting material must evidently vary quite as much from the operation of external causes as from the form of the land surface upon which it is built up.

This fact emphasizes the necessity of considering in detail the possibilities of origin of the substance in any given deposit before deciding to use it for any given purpose, in order to find how much of the entire amount is available for the desired use.

PRACTICAL APPLICATION OF THE PRINCIPLES OF PEAT FORMATION.

Aside from the purely scientific interest attaching to the study of the origin of peat is the consideration of the practical and economic utilization of individual deposits. In fact, only by knowing under what general laws the substance is developed can statement be made as to whether a given deposit of peat can be used profitably for certain special purposes. To illustrate, after brief preliminary tests, with a properly constructed sampling tool, the laws governing the accumulation of peat can be applied to any bog with sufficient precision to determine to which general class it belongs, and whether it may be drained to the bottom.

Filled depressions can not be drained lower than the bottom of the existing outlet, except at great expense, or under very unusual conditions, so that any peat deposit of this type can be more cheaply worked without attempting drainage.

Where the structure of the peat, as determined by preliminary tests, shows that it has been built up layer upon layer, on a flat area, it can manifestly be drained to the very bottom of the deposit, and by beginning at the outlet, or lower end, can be drained by easy stages, as utilization progresses.

Application of the same laws to the structure of bogs will demonstrate that the peat of mature bogs in filled depressions is never of the same structure from top to bottom, since it has been formed by plants growing partly below and partly above water level. Moreover, the lower strata of the peat are of much greater fineness than the upper and are almost, if not quite, free from fibrous matter of all sorts, and are not adapted for any use requiring a large proportion of fiber. The latter will be found only in that part of the peat formed above, or immediately below, the water level, and will be at most only a few feet thick.

On the other hand, built-up bogs may be composed of the same sort of material for the greater part of their thickness, since the ground water level of the deposit may always have been in a definite relation to the surface of the peat. It is generally true that such bogs rarely exceed 15 feet in depth even when they cover very wide areas, and they are much more likely to include woody layers containing stumps and roots of trees than those of the other type.

The same general statements are applicable to deposits formed by the subsidence of the bottom on which they are built, with the additional assertion that such deposits contain a large percentage of silt where they lie below tide level, and hence are of low fuel value.

PHYSICAL AND CHEMICAL PROPERTIES OF PEAT AS RELATED TO ITS FUEL VALUE.

PHYSICAL PROPERTIES.

Peat as it is found in undrained bogs is a mixture of water and of partly decayed and disintegrated vegetable matter of varied origin. The amount of water present is generally sufficient to saturate or supersaturate the vegetable material and constitutes from 85 to 95 per cent or even more of the weight of the mixture.

Even in drained bogs a short distance away from the ditches the water content seldom falls below 80 per cent, as the rain falling on the surface is quickly absorbed by the mass of the peat, through which it drains very slowly. The slow movement of water to the ditches in peat beds is shown by the fact that for a considerable distance above the water level in the ditches, or even when no water is standing in them, water can usually be squeezed from the material taken from their walls.

Aside from this generally high water content, peat is exceedingly variable, so that scarcely any two deposits contain material which is exactly similar in all of its physical properties. These properties also normally vary in peat from different regions. Material from the north may be quite dissimilar in appearance and other physical properties from that farther south, east, or west, because not only are the kinds of plants from which it was derived different, but also the climatic effects on their accumulated remains during deposition. It also must be apparent from the discussion of the ways in which peat is formed, that peat in bogs of distinct types in the same region must differ physically because the conditions of accumulation and the original vegetable matter must be different. Considering the matter still further, it may be shown that the upper layers of peat in a given deposit are often distinct in many of their properties from those below them, and in the bogs that fill depressions are practically always so.

The considerable variation in the properties of peat is due to many causes, the most important of which have been briefly discussed. Although this variability is unimportant to those who propose to prepare peat for fuel by any of the simpler methods, it must be carefully considered by all who intend to use the material for special purposes or processes because of the relatively small quantity of the required kind of material that may be found in a given peat deposit. Not only must the limited quantity be taken into account, but when fiber or similar material is sought for the

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manufacture of certain kinds of products there must be considered, also, the quantity and probable condition of the fiber and the proportion thereof that can be used as compared with the material to be excavated and handled to recover the usable part. By no means of least importance, also, is the cost of production and the value of the final product when compared with that obtained from other substances already in use.

COLOR.

In color peat ranges from light-yellowish or straw tints through various shades of yellowish brown, reddish brown, and dark brown to jet black. All of these colors are darker when the peat is wet, but the lighter shades usually change to black or dark brown after the peat is macerated and exposed to the air. The color sometimes darkens immediately after the freshly cut sample comes in contact with the air and before it dries to any appreciable extent.

In general, the top strata of a given deposit that has a low water level will be black or dark colored, whereas those below the water level will be lighter in color, but in a built-up deposit there may be dark-colored strata interbedded with or lying below lighter ones.

It is seemingly true that all beds of peat to which the air has had access have been blackened or at least darkened in color, and it is only in such beds as have been dried out to the bottom and thoroughly aerated that a progressive darkening from the top to the bottom is found. The blackening is due to the oxidizing of the more complex organic compounds to simpler ones and the liberation of certain gaseous constituents of the vegetable matter, largely by biochemical activities of low organisms, chiefly plants. The oxidation tends to concentrate the carbon of the plant débris in its simpler dark-colored or black compounds, which give the color to the resulting mass.

Peat that is greenish when wet or that is gray, rusty, or spotted with white when dry, or that is unduly heavy, owes these characteristics to the presence of mineral matter and is probably unsuited for fuel for ordinary purposes. Rarely, however, do appearance and color of peat, even in the dry state, indicate whether or not it contains mineral matter enough to render it useless, except when silt and sand grains are present in sufficient numbers to be seen on close inspection of the dry sample. Such material should be looked upon with suspicion and carefully tested before using. A report from Mexico, where fuel is high priced, states that peat that has been washed to free it from sand is marketed with profit.

TEXTURE.

The texture naturally depends upon the kinds of plants from which the peat is formed and the conditions under which their remains have accumulated. If the original vegetation was largely trees and shrubs growing slightly above the level of the water, the peat is woody. If

the growing plants were of grass-like structure with tough, fibrous leaves, stems, and roots built into a compact turf near the water level, the peat derived from them is fibrous and generally poorly decomposed. If such materials have accumulated much above the preserving effect of the water, the fibrous structure may be lost and the whole be uniformly of fine grain. Grass and sedge peat, in shallow deposits in those parts of the country where there are prolonged summer droughts, are often so thoroughly decomposed as to be almost without fibrous matter, except such as is furnished by the roots of plants growing upon the surface of the bog.

Mosses, including *Sphagnum*, the so-called peat moss, are without fibrous tissues of any sort, although their stems are somewhat durable under ordinary bog conditions, so that true moss peat, even when poorly decomposed, does not furnish fibrous material. Peat of this sort is of rare occurrence, however, and the mixed moss and sedge peat of the northern and northeastern parts of the United States often has considerable tough, fibrous matter derived from cotton grasses, *Eriophorum*, and other sedges.

The water plants, because of their lack of fibrous and durable tissues and of the conditions under which they grow and decay, form a structureless, cheesy substance, lacking both wood and fiber, except where there is an admixture of drift material from land plants, as sometimes happens. The bottom layers of filled bogs, therefore, are made up of soft, oozy peat, and are worthless as sources of fiber for any purpose, but, conversely, may make better fuel than more fibrous types.

It is apparent, then, that the texture and uniformity of peat in a given deposit depend upon (1) the kind of bog, whether filled or built up; (2) the general types of plants whose remains have been incorporated in the peat; (3) the completeness of their disintegration, which is in large measure controlled by the position of the ground-water level relative to the surface during the formation of the deposit. The disintegration is indicated in general by the shade of coloration, the more thoroughly disintegrated material being the darker.

Variability in the texture of peat, as has been indicated elsewhere, is the rule, even in parts of the same bog. Bogs of very moist regions, like those of the northern and northeastern parts of the United States, are less likely to show large variations than are those occurring where periods of heavy rainfall alternate with droughts. In the latter regions there are frequent changes in the conditions of growth of the vegetation, and in the conditions attendant upon the decay of the resulting collections of débris. Thus the peat beds of the South and the Middle West, having been formed under the last-named conditions, are likely to be more woody and less fibrous, as well as much more thoroughly decomposed, than those of similar types found elsewhere in this country.

COMPOSITION.

For purposes of this discussion, the solid material found in peat beds may be considered as regards origin to be of two sorts—organic and inorganic. The first includes such material as has been accumulated by the life processes of plant and animal organisms, the second includes extraneous mineral matter present as impurities and generally not directly traceable to the activities of organisms. Each of these groups may be subdivided into two others—soluble and insoluble material. Group 1 may be subdivided still further into carbonaceous matter and mineral matter, the former being combustible and the latter incombustible and constituting the ash-forming substances of the peat.

The carbonaceous or combustible portion of peat is chiefly of vegetable origin. Doubtless, however, the more durable parts of many small animals, especially insects and crustaceans, enter into the composition of types of peat formed below water level, and sometimes may be present in sufficient quantities to give to the smoke from burning peat a distinct trace of the characteristic odor of burning chitin.

The purely vegetable constituents of peats are generally in various stages of disintegration and division as the result of chemical decomposition and physical maceration of the original plant tissues from which they have been derived. A part of this comminution is purely mechanical, the result of the action of wind, water, and other forces on the material before it reached the place of final deposition; some of it results from combined mechanical and chemical action, and some appears to come from chemical action of air and water. Much of it is due to biochemical agencies, as many kinds of animals and of plants, including the bacteria and fungi, as well as the roots and other underground organs of higher plants, play some part in the reduction of the highly complex plant material to the structureless pulp of well-decomposed peat. In the disintegration due to the chemical agencies actual changes of composition occur in the chemical compounds of the plant tissues concerned. A part of their constituents form new and simpler compounds, some of which are soluble and some are gaseous. The soluble ones are taken up by the water, to which they impart a distinct color and often an acid reaction; the gases escape into the air, either imperceptibly or in the form of bubbles, or are absorbed by or dissolved in the water.

As would be expected, it seems generally true that the herbaceous plants and the softer and less woody parts of other plants are most easily broken up, and their fragments enter largely into the composition of the finer matter of peat beds. On the other hand, woody and fibrous tissues are often found to contribute abundantly to such material, but some of the algæ and mosses seem very little subject to disintegration, although of exceedingly delicate texture. As is gen-

erally known, well-preserved roots, stumps, and boles of trees, and, to a less degree, of shrubs, are common in peat beds. In all cases, however, peat that has been exposed in a moist condition to the air, and has been subjected to the invasion of the soil fungi and bacteria and the attacks of low types of animals, is most nearly structureless; that which has been continuously covered by or saturated with water often contains very fragile and delicate plant organs preserved entire.

The mineral matter that has been segregated in peat beds by organisms varies greatly in form and quantity. Of the total dry weight, the purest peat contains only 2 or 3 per cent in the form of mineral matter, although such a small proportion is unusual, and from this minimum we find every gradation to pure mineral soil. In those deposits in which the quantity of mineral matter is small, it has usually been collected and deposited by the plants of which the peat has been formed and by the animals associated with them; that is, it is all of organic origin. The assumption can not be made without investigation that where a large amount of mineral matter is found it has not been concentrated by the same sort of agents, because in limestone regions much calcareous matter is secreted from the ground waters by water plants (especially by *Chara* and more minute algæ) and deposited with the carbonaceous matter, or in excess of it in some cases. In addition, many types of plants growing in the water or in wet places deposit considerable quantities of silica in their cell walls. The diatoms, very minute water plants often enormously abundant in lakes and ponds, the scouring rushes or horsetails, *Equisetum*, grasses and sedges, and many of the higher plants are examples of this type. Many kinds of plants are also known to collect as crystals in the walls and cavities of their cells and tissues more or less mineral matter of other kinds than those mentioned. Animals contribute bones, teeth, and shells varying in size and composition from the calcareous bones of the gigantic extinct elephants, the mastodon and the mammoth, to the minute siliceous shells of microscopic water animals.

The mineral matter of peat, which can not be considered as of organic origin, is derived from two principal sources. It is either brought in by the water or blown in from the surrounding land. The water-transported material is carried to the peat either in suspension or in solution. In general, the amount of deposition from suspension is much greater and of much more importance than that from solution, because it may be considered to include not only finely divided mineral matter transported by waves and currents, but the coarser rock fragments floating about supported by ice masses. Stones and pebbles, as well as the finer sands, silts, and muds, are thus borne into peat beds and left at times of high water, and in all deposits subject to overflow from streams, lakes, or the ocean, a greater or less quantity of such material will be found.

What might be important sources of fuel supply are often rendered unfit for use for this purpose by the great amount of incombustible matter brought to them by some small stream, or their prospective value is greatly lessened by the presence of stones, which limit the use of machinery.

The dissolved mineral substances brought to peat beds are of less importance than the kinds considered, but if they are sufficiently abundant they serve as sources of supply for their precipitation by organisms, as already mentioned; or they may be chemically precipitated in the peat as insoluble substances, or be concentrated by the evaporation of the water from the surface of the peat, and thus become important impurities. Iron sulphide, often found in peat, is an example of a chemically precipitated substance. The ferrous sulphate and the salts of magnesium and calcium which accumulate in peat subject to overflow by spring and pond waters rich in mineral matter or lying above beds of marl may also be taken as illustrations of concentration due to evaporation. Much of the mineral matter brought to peat in solution is retained because only the water evaporates, and appears in the ash after the peat is burned; hence the peat in regions where the ground water is mineralized, as where limestone predominates, is likely to have more ash than that of areas of pure water such as occur in granitic regions.

The material brought to peat beds by the wind is chiefly fine dust. Such material constitutes an important part of the ash in peat along the border of the great plains region, but is practically lacking in peat from the moister parts of the United States. Along the shores of the ocean and the Great Lakes, where bogs are formed in hollows between lines of sand dunes, sand is often blown into the peat during storms, and peat deposits of this type may contain much sand.

WATER-HOLDING CAPACITY.

From what has already been said, it is apparent that peat has great capacity for taking up and holding water. In fact, the bogs of Europe and especially of Ireland often become greatly swollen during rainy seasons and sometimes burst and flood the surrounding country with pasty peat and water.

The water present in peat appears to be held by the plant remains in three ways, two of which are mechanical. Of the mechanically held water a part only is removable by pressure or other mechanical means. Prolonged trials made by many competent experimenters show that only a relatively small per cent of the water can be pressed from peat having at the outset 90 per cent moisture, that is, about the quantity found in peat as it lies in the bog. The remainder of the included water resists the greatest obtainable hydraulic pressure and the best centrifugal machines, and can be removed only by evaporation. If the quantity present originally is below 90 per cent,

the percentage removable by pressure is correspondingly reduced. In other words, the removal of the water that can be pressed from peat does not reduce its water content much below 70 per cent, and the rest can be driven off only by heat, derived either from the sun and air or, more expensively, from an artificial source. This residual water is largely held in the cell walls and the minute cavities of the cells of the plant remains. It is clearly not held in chemical combination, as it can be entirely removed by gentle heat without destroying the nature and structure of the peat. After drying under proper conditions, the peat will again take up water and will assume its former appearance and condition; drying destroys the cementing compounds in the peat, however, and peat that has been once dried out, even if again thoroughly wet, will not make good machine-peat bricks.

The quantity of water thus held in peat varies somewhat, being less in black, thoroughly decomposed types than in the more fibrous brown ones, but the variation does not seem to be very large, and does not warrant the attempt to use pressure for completely removing water from any kind of peat. Thorough maceration or grinding also has the effect of rendering the water more free in its movement in the peat. This effect is probably due to increased uniformity of texture thus produced and not to breaking up the cells of the plant remains, as these are exceedingly minute and would not be much affected by the coarse machinery commonly used for grinding peat.

After thorough maceration and puddling, if the peat mass is allowed to dry slowly to an air-dry condition, it contracts in bulk and dries into a hard and firm substance that absorbs very little water even if thoroughly immersed. Untreated peat, on the other hand, dries into a loosely aggregated mass, which takes up water readily and is very friable and easily broken up in either wet or dry states.

Peat that has been dried below the air-dry condition quickly absorbs moisture from the air until it is again air dry, and its moisture content then varies with the relative amount of moisture in the air, so that air-dried peat contains a lower percentage of water in a dry climate than in a moist one, or in dry weather than in wet.

WEIGHT, DENSITY, AND SPECIFIC GRAVITY.

The different types of peat, as is indicated by their differences in structure and appearance, vary considerably in weight for a given unit of volume. They also vary in specific gravity; that is, their weight compared with that of an equal bulk of pure water which is taken as unity. The actual specific gravity of plant fiber, and of peat substance derived from it, is greater than unity; hence these materials free from air and other included buoyant matter would sink when placed in water. Under ordinary circumstances, however,

because of the many open spaces and air-containing cavities in peat, the specific gravity, as obtained, is generally much less than unity. The figures determined for the dried peat substances range from about 0.1 for very fibrous, light-colored, and poorly decomposed moss peat to 1.06 for the heavy, compact, fine-grained, thoroughly decomposed black kinds, which, when dry, are almost as hard and black as bituminous coal. The darker brown, fibrous, and partly decomposed types are intermediate in character, and their specific gravity varies from 0.25 to 0.70, or even more, if it happens that there is much included mineral matter.

The actual dry weights of these grades per cubic foot are, for the lighter and undecomposed fibrous kinds of moss and sedge peats, 7 to 16 pounds. For the brown and dark brown and more thoroughly disintegrated types the weight ranges from about 15 to 45 pounds per cubic foot. The dense, black, nonfibrous kinds that are thoroughly decomposed weigh from about 40 to more than 60 pounds per cubic foot of dry matter. These weights will be increased if the ash content rises above 15 per cent of the total weight of the dry peat, as the mineral matter of the ash has a high specific gravity. Therefore, before any other tests are made, peats that are very heavy and compact when dry should be examined to see if they do not contain too much ash for fuel purposes.

In order to get the true weight of a cubic foot of peat, the mass weighed should be as compact as possible without compression, since if the dry material be in the form of lumps or of disintegrated fibers, air spaces will take up a considerable part of the measure, and the weight obtained will be too small.

It may be noted therefore that the fibrous, light-colored, and poorly decomposed peats are light in weight when compared with the darker homogeneous, and more thoroughly decomposed kinds, and make more bulky and less easily transported and stored fuel and require much more thorough maceration to reduce them to a satisfactory condition for general use.

RELATIONS OF THE PHYSICAL CONDITION OF INCLUDED VEGETABLE MATTER TO EXPLOITATION.

The availability of a given peat deposit for certain definite prospective uses depends much upon the physical condition of the plant remains contained in the peat. Thus, if the peat is to be used for making paper or stable litter there should preferably be a large amount of well-preserved, fibrous matter available, whereas fine-grained, structureless, compact peat, so desirable for fuel, must be rejected. If the peat contains layers of well-preserved woody plant structures, especially roots and logs, the cost of preparing the bog for working is increased and its actual exploitation is rendered costly and slow

unless powerful machinery be used. Peat containing much tough, fibrous matter is often difficult to grind in the usual type of peat machine because the knives become clogged by the fibers. Poorly disintegrated grassy and mossy peat is not suitable for most types of briquetting machines, because the briquets made from it are very light in weight and particularly likely to break up into thin plates when handled or when in the fire. Therefore, it is very desirable and even essential to learn as much as possible of the physical properties that are necessary to insure success in some chosen field of exploitation. A quality of peat which is adapted to the use should then be sought.

CLASSIFICATION BY PHYSICAL CHARACTERS.

It is quite evident from what has already been written that a classification of peats may be based upon purely physical properties, but when such classification is attempted it is difficult to draw sharp lines, so that a number of systems of characterizing peat are in common use. In most of these a compound terminology combining color, structure, and weight is used, but a quite different terminology is also used, which characterizes the material according to the kind of vegetation that is most conspicuously preserved in it or is found growing on the surface.

In this connection muck should be mentioned. The term "muck" is frequently used as distinct from peat to characterize peaty soils high in mineral matter, but in general it is applied by farmers of all parts of the country to swamp soils which, by their color, indicate a considerable, or high, per cent of organic matter, whether they are pure vegetable substances or not. In fact, the word "peat" is often unknown, except as a book word, in districts in which there are good peat beds of considerable extent, muck being the only name given such deposits.

Johnson [a] gives the following classification of peats cited from a German writer:

(a) *Turfy peat.*—Consisting of slightly decomposed mosses and other peat-producing plants, having a yellow or yellowish-brown color, very soft, spongy, and elastic; specific gravity, 0.11 to 0.26, the full English cubic foot weighing from 7 to 16 pounds.

(b) *Fibrous peat.*—Unripe peat which is brown or black in color, less elastic than turfy peat, the fibers either of moss, grass, roots, leaves, or wood, distinguishable by the eye, but brittle and easily broken; specific gravity 0.24 to 0.67, the full cubic foot weighing, accordingly, from 15 to 42 pounds.

(c) *Earthy peat.*—Nearly or altogether destitute of fibrous structure, drying to earth-like masses which break with more or less difficulty, giving lusterless surfaces of fracture; specific gravity, 0.41 to 0. 90, the full cubic foot weighing from 25 to 56 pounds.

(d) *Pitchy peat.*—Dense; when dry, hard; often resisting the blows of a hammer, breaking with a smooth, sometimes lustrous fracture into sharp-angled pieces; specific gravity, 0.62 to 1.03, the full cubic foot weighing from 38 to 65 pounds.

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[a] Johnson, S. W., Peat and Its uses. New York, 1866, pp. 95-96.

CHEMICAL PROPERTIES.

GENERAL COMPOSITION.

Primarily, the organic materials from which peat originates are two—cellulose, or ordinary vegetable substance, and lignin, or woody matter. Both of these are complicated chemical compounds of the solid element carbon and the gases oxygen and hydrogen, and as found in plant tissues contain also mineral substances in considerable variety. They are often mixed with lesser quantities of other organic compounds which have been formed in the course of the activities of the living plants, such as resins, fatty and waxy bodies, and others which contain nitrogen, the inert gaseous element of air.

During the decomposition of these substances, which, as already pointed out, is largely accomplished by the activities of fungi, bacteria, and other organisms, new and simpler but still complicated substances are formed. The latter have never been exhaustively studied, although from time to time some of the more generally distributed groups of such compounds have been investigated. Several substances possessing acid properties that have been isolated from peat have been named. In this class are humic, ulmic, geic, crenic, pectic, and other acids; humin, ulmin, etc., are names given to other types of substances known to occur in peat, but difficult to obtain from it. By some writers these compounds are all classed together under the comprehensive name of humus. The plant organs composed of pure cellulose seem to be least affected by decomposition. Thus fine rootlets, epidermal cells of herbs, etc., often occur well preserved in peats from which all other structures have disappeared.

It is generally understood by chemists, however, that the above names do not correspond to single compounds, but rather to groups of related bodies which possess similar chemical properties. Bituminous and resinous matters are also found under natural conditions in some types of peat, especially in such as are thoroughly decomposed and blackened, most often under conditions that lead to the conclusion that they are concentration and not decomposition products.

During the processes of decomposition of vegetable matter, as they ordinarily go on in a peat bog, a part of the gaseous elements oxygen and hydrogen, together with a part of the carbon, is liberated from the less resistant organic compounds in the form of gases. Of these gases, carbon dioxide (CO_2), made up of carbon and oxygen, and marsh gas or methane (CH_4), a simple compound of carbon and hydrogen, are those most frequently observed. Together with nitrogen, and less often hydrogen-sulphide, the gases referred to form the bubbles of gas so abundantly given off when vegetable matter undergoing decay under water is disturbed, and by their formation and escape they reduce the proportion of oxygen to the carbon. Hence the more completely decomposed peats have a higher percentage of

carbon and less oxygen and hydrogen than those in which the vegetable matter is more nearly in its original state. This is well shown in the tables of analyses (see p. 186) made by the United States Geological Survey.

CHEMICAL COMPOSITION OF THE ASH.

As the ash of peat is extremely variable in quantity and in origin, so also it varies greatly in chemical composition. When the ash exceeds from 3 to 8 per cent of the dry weight the excess may commonly be attributed to the action of water or wind or both.

The quantity of ash directly traceable to the plants varies, however, according to the kinds of plants from which the peat originated, its state of decomposition, and the quantity of mineral matter carried in solution in the water with which it is saturated. Thus peat formed from trees and other woody plants will generally have a higher normal percentage of ash than that derived from grasses and similar plants. Such peat in turn will be somewhat richer in silica, calcium compounds, and other mineral matter than that in which mosses are the principal sources of the original plant material.

As the peat loses its more volatile constituents the proportion of mineral matter or ash will, as is clear, steadily increase by reason of the concentration of the solid constituents. Chemical analysis has also demonstrated that in regions where the soil waters contain much mineral matter in solution plants of a given species contain a higher percentage of ash than those of the same species grown where the water has less soluble matter. Thus in limestone regions the ash of most plants is found to contain more lime, or calcium sulphate, than occurs in the same species in regions of granitic rocks.

As a rule the mineral matter of extraneous origin which is found in peat ash is largely silica in the form of sand and silt, or is alumina and silica in the form of clay. It may, however, be principally calcium carbonate or sulphate where these minerals are abundant in the rocks or in the derived soil and soil water. Iron is not infrequently abundant in the peat as organic compounds, humates, etc., or as the sulphate, sulphide, carbonate, or oxide. Ferrous sulphate is sometimes abundant in peat beds formed where the water supply is chiefly derived from springs, and indicates its presence by giving off strongly acid fumes when the peat is burned and by imparting a whitish or greenish coating to the partly dried peat. All iron compounds give to the ashes of the peat a rusty or reddish color. As already noted above, the silica or the calcium carbonate in pond-formed peat may be largely of organic origin.

The following analyses [a] of ashes of peat from Connecticut bogs show their variable character.

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[a] Johnson, op. cit., pp. 47–49.

Analyses of ashes of peat from Connecticut bogs.

Constituents.	Name of sample.			Constituents.	Name of sample.		
	A.	B.	C.		A.	B.	C.
Potash...................	0.69	0.80	3.46	Sulphuric acid............	5.52	10.41	4.04
Soda....................	.58	....	Trace.	Chlorine.................	0.15	0.43	0.70
Lime....................	40.52	35.59	6.60	Soluble silica............	8.23	1.40	67.01
Magnesia................	6.06	4.92	1.05	Carbonic acid............	19.60	22.28	67.01
Oxides of iron and alumi-				Sand....................	12.11	15.04	67.01
num...................	5.17	9.08	15.59				
Phosphoric acid..........	.50	.77	1.55		99.13	100.74	100.00

The range of the components compiled by the same author from various sources, chiefly European, is as follows:

Variations and averages in composition of peat ashes.

Chemical compound.	Minimum.		Maximum.		Average.	
	Per cent.	Pounds per ton.	Per cent.	Pounds per ton.	Per cent.	Pounds per ton.
Potash.............................	0.05	1.0	3.64	72.8	0.89	17.8
Soda..............................	None.	.0	5.73	114.6	.83	16.6
Lime..............................	4.72	94.4	58.38	1,167.6	24.00	480.0
Magnesia..........................	None.	.0	24.39	487.8	3.20	64.0
Alumina...........................	.90	18.0	20.50	410.0	5.78	115.6
Oxide of iron......................	None.	.0	73.33	1,466.6	18.70	374.0
Sulphuric acid.....................	None.	.0	37.40	748.0	7.50	150.0
Chlorine...........................	None.	.0	6.50	130.0	.60	12.0
Phosphoric acid....................	None.	.0	6.29	125.8	2.56	51.2
Sand..............................	.99	19.8	56.97	1,139.4	25.50	510.0

It should be noted that in peats of low ash content the percentage of constitutents of agricultural value will generally be higher than in those having much ash, because such peat is derived from nearly pure vegetable matter in which there is a degree of concentration of potash and phosphoric-acid salts which does not exist in soil waters or in the finely divided mineral matter borne about in suspension in lakes and streams or in the air.

RELATION OF ASH TO FUEL VALUE.

The quantity of ash determines within certain limits the value of peat for commercial fuel purposes, because the analyses accompanying this report (pp. 186–203) clearly show that the fuel value is decreased nearly in direct proportion to the increase in the amount of ash within these limits.

This is due theoretically to the following reasons: The ash displaces a definite amount of combustible matter so that a given weight of peat with much ash contains less actual substance from which heat can be generated than the same weight of purer material. The ash requires and uses up heat to raise and maintain its own temperature to that of the surrounding combustibles. Heat energy is also used to bring about many of the chemical changes that the fire may cause in the

ash constituents. In the latter respect silica and other substances chemically unchanged by heat produce no effect.

The maximum quantity of ash usually considered allowable in peat that is to be sold for fuel on a commercial scale is somewhat arbitrarily placed by some writers at 25 per cent of the total dry weight and by others at 20 per cent. Peat with less than 5 per cent ash is regarded by the Irish authorities as good, that having from 5 to 10 per cent as moderately good, and that having from 10 to 25 per cent as bad. The Swedish standards are as follows: Low, 2 per cent; average, 5 per cent; comparatively high, 8 per cent; high, 11 per cent; very high, 14 per cent.

These limits are fixed because the calorific value of material with more than 20 per cent ash is assumed to be too low for commercial use. Below this limit, however, peat of high ash content is often found which exceeds in its theoretical fuel value, as shown by calorimeter tests, peat with a much smaller percentage. Peat with a proportion of ash much greater than 20 per cent may doubtless be used without detriment for the generation of producer gas than for burning as ordinary fuel.

Enthusiastic advocates of the use of peat fuel have made some absurd claims regarding the value of peat compared with other kinds of fuel now in common use. The basis for all adequate fuel comparisons, however, must be chemical analyses and calorimetric determinations, followed where possible by actual working tests conducted under standard conditions by impartial and well-trained engineers.

It should be pointed out, on the other hand, that all tests are of relative rather than absolute value; they form a reliable foundation upon which to base judgments, and therefore are justified and of immeasurably greater value for practical operations than mere opinions derived from superficial personal observation and experience.

PROXIMATE AND ULTIMATE ANALYSES.

There are two kinds of experimental work for determining the relative value of fuels of the same or different kinds: (1) the chemical and fuel analyses of small samples, and (2) test runs made with large quantities under conditions reproducing as closely as possible those under which the fuel is used commercially.

Chemical analyses of fuel are of two kinds, proximate and ultimate. In the former the moisture or free water contained in the fuel, the volatile matter, including chemically combined water and the hydrocarbons, the nonvolatile or fixed carbon, and the ash are determined under approximately fixed conditions. The included water is first driven off by heating a carefully weighed sample of the material at about the temperature of boiling water, the heating being continued until repeated weighings show no further loss of weight. If the substance contains much very volatile matter the water is often removed

by heating under reduced pressure or by exposure to dry air at a low temperature (about 100° F.). In making the analyses of peat that accompany this report it was found necessary to take these precautions.

The volatile matter, chiefly hydrocarbons, is next driven off from the sample in the form of permanent gases and liquids by raising the temperature enough to insure the decomposition of the fuel and the vaporization of the newly formed compounds of carbon and hydrogen, care being taken to exclude the air so that the residue of carbon does not take fire. After the evolution of the gases has ceased, as shown by the dying out of the flame above the dish in which the heating is done, the carbon residue and dish are cooled and again weighed. The difference in weight from that previously found shows the quantity of the volatile matter; the weight of the residue is that of the coke.

The coke is once more strongly heated in a plentiful supply of air until all traces of the black color of the carbon disappear, leaving only the ash. The difference between the weight of the coke and that of the ash is fixed carbon. The weighings are always made after the dish and the substance contained in it are cold. In such analyses it is apparent that no effort is made to find out what substances are present, the whole operation being on a small scale similar to the processes going on in any fire box while combustion is taking place.

In ultimate analyses, on the other hand, the substance is broken up into its constituent elements by proper chemical processes, and the amount of each is determined as exactly as possible. The methods employed are somewhat complicated and require great care and special chemical knowledge, and need not be described here. The results of such work are much more definite than those of the other class and state exactly the proportions of the elements that are present in the substance under examination. In ultimate analyses of fuels it is not usual to fully analyze the ash.

DETERMINATION OF CALORIFIC VALUE.

Besides these two kinds of chemical analyses the theoretical calorific or heat value of fuels is determined by direct experiment, or by calculation from the ultimate analysis. The results of either method are expressed in thermal or heat units.

A thermal unit is the quantity of heat required to raise the temperature of a given weight of a selected substance a specified amount. The thermal units in general use among physicists, engineers, and others are the British and the French or continental. The British thermal unit (B. t. u.) is the quantity of heat required to raise the temperature of a pound of water 1° F. The French unit (calorie) is based on the centigrade thermometer scale and the metric system

of weights. The gram calorie, or small calorie (cal.), is the amount of heat required to raise the temperature of 1 gram of water 1° C., and the kilogram calorie, or large calorie (Cal.), is the amount of heat required to raise the temperature of 1 kilogram of water 1° C. Another thermal unit sometimes used is the pound calorie, the amount of heat required to raise the temperature of 1 pound of water 1° C.

The calorific value of a fuel is measured by the power of a given weight of the fuel to heat a given weight of water. Manifestly, 1 gram of a fuel will heat 1 gram of water to just the same degree that 1 pound of the fuel will heat 1 pound of water. Hence if the weights of fuel burned and of water heated are expressed in the same units, the relation between the British and the French thermal units becomes that of the thermometric scales. In other words, if grams (or kilograms) of fuel are burned to heat grams (or kilograms) of water, the gram (or kilogram) calories thus determined may be converted to British thermal units per pound by multiplying by 1.8, because a centigrade degree is 1.8 times as large as a Fahrenheit degree.

If, however, a constant weight (for instance, 1 lb.) of fuel be used, and the large calorie (the amount of heat necessary to raise the temperature of 1 kg. of water 1° C.) be compared with the British thermal unit (the amount of heat required to raise 1 lb. of water 1° F.), account must be taken not only of the different thermometric scales, but of the kilogram being 2.2 times the weight of the pound; hence the number of large calories in 1 pound of fuel is equal to $1.8 \times 2.2 = 3.96$ times the number of British thermal units.

The calorific value of a given fuel may be determined directly from an average sample by the use of a calorimeter, or by calculation from the ultimate analysis. The calorimeter is a carefully constructed instrument, in one type of which a small quantity of the finely powdered fuel to be tested is completely burned in a closed metal vessel or bomb, entirely surrounded by water, which absorbs the heat generated by the combustion. Complete combustion is insured by the addition of pure oxygen gas or oxygen-bearing chemicals to the sample in the bomb. The resulting rise in temperature is measured by an accurate, finely graduated thermometer. To prevent temperature changes due to outside influences, the whole apparatus is protected when in use by a heavy nonconducting covering,[a] and is used in a uniformly heated, closed room.

The calorific value of a given peat sample, stated in terms of the theoretically dry peat, may be reduced to that of any desired water content or percentage of moisture between 0 and 30 per cent, sufficiently near for ordinary commercial use, by deducting 1 per cent

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a For a description of the methods used in chemical and calorimetric work on fuels in the chemical laboratory of the technologic branch of the United States Geological Survey and in the chemical laboratory of the Bureau of Mines, the reader is referred to Technical Paper 8 of the bureau.

from the theoretical calorific value for each per cent of moisture assumed to be present. Conversely, if the thermal value of peat with a given percentage of moisture is known, the thermal value of the same peat on the theoretically dry basis can be calculated. In practice this is reduced to a formula as follows:

$$\frac{\text{Calorific value as analyzed}}{100 - \text{percentage of water found by analysis}} \times 100 = \begin{array}{c}\text{Calorific value of the}\\ \text{moisture-free peat.}\end{array}$$

The calorific value of a fuel of which an ultimate analysis has been made may be obtained by the use of formulas in which the percentages of the heat-giving elements of the compound under examination are properly combined with fuel values of the pure elements. The latter have been so often determined that they are accurately known and may be used as constants.

To secure uniformity of statement in comparing fuel values, many analyses have been published showing the number of heat units obtainable from different kinds of fuel under theoretical conditions. Such statements are often misleading to the general reader, especially when they are given in terms of the water-and-ash-free substance, or as if the fuel were entirely made up of combustibles—a purely hypothetical condition which makes the efficiency of the fuel appear too high. On this basis, adopted to secure the uniformity of statement that is essential for accurate comparison of fuels of the same kind, the error is not uniformly distributed when comparisons are made of widely varying classes of fuels, because those which always have high percentages of ash and water may be given false values by recalculating them. On the other hand, there are other kinds of fuel which are always low in ash and contain smaller percentages of water and their analyses show but little change when recalculated.

For these reasons the following calorific values of mineral fuels are all chosen to indicate as nearly as possible their fuel value in the condition in which they are found in the market. The determinations were made at the chemical laboratories of the technologic branch of the United States Geological Survey. They are from samples carefully taken from carload lots of commercially well-known coals and other substances which were sent to the fuel-testing plants of the survey for experimental and testing work.

The peat samples were analyzed at the same laboratories and by the same methods as the coals. The method of collecting the peat samples was slightly modified for different field seasons, but in general the samples analyzed were taken at 2-foot intervals from several rather widely separated test holes extending from top to bottom of the deposit. The samples were sufficiently well mixed to insure that each was an average of the deposit. The collections were made with a sampling tool devised by the writer. This tool permits

the taking of pure samples at any desired depth, and has proved so generally useful and accurate that it is described on pages 71 and 72.

In the early part of the work samples were sent to the laboratory in a wet state, but the difficulty of obtaining water-tight containers of the right size led to the adoption of the plan of collecting a large sample for the usual analyses in a cloth bag. A small sample from which the water content of the peat at the time of its collection could be determined was also collected in a 4-ounce bottle, provided with a suitable mailing case. The sample in the bag soon dries down to a low percentage of moisture and can then be mailed without difficulty.

It is evident that analyses made from samples taken in this way are of more general value than those made from carefully selected materials or from those which have been taken from single stations or beds.

Calorific value of the common types of fuel compared with air-dried peat.

COMMON TYPES OF FUEL.

Lab. No.	Type of fuel.	Locality.	H₂O.	Ash.	Sulphur.	Heating value.	
						Calories.	B. t. u.
3216	Graphitic anthracite...	Cranston, R. I......	2.41	19.06	0.07	6,109	10,996
a 519	Coke...............	Mixed coke.........	6.55	12.86	.97	6,870	12,366
	Anthracite...........	St. Nicholas, Pa.....	2.30	13.39	1.05	6,975	12,523
4287	.....do...............	Blacksburg, Va.....	4.80	17.64	.84	6,645	11,961
2744	Semianthracite........	Spadra, Ark.........	5.19	14.01	2.05	6,922	12,460
5829	Semibituminous(Pocahontas No. 3).	Ennis, W. Va.......	3.67	6.55	.46	7,939	14,290
4609	Bituminous (Pittsburgh).	Connellsville, Pa....	5.13	8.71	.86	7,525	13,365
2020	Bituminous (Illinois)..	Zeigler, Ill..........	10.72	9.36	.52	6,492	11,686
1779	.....do...............	La Salle, Ill.........	12.39	8.92	3.92	6,333	11,399
3396	Bituminous (Wyoming).	Hanna, Wyo........	12.40	6.77	.26	5,948	10,706
2734	Lignite (Texas)........	Olsen, Tex..........	31.06	7.88	.99	4,372	7,870
2243	Lignite (North Dakota)	Wilton, N. Dak.....	35.96	7.75	1.15	3,927	7,069

a Test number.

AIR-DRIED PEAT.

Lab. No.	Kind of peat.	Locality.	Water.	Ash.	Sulphur.	Heating value.		
						Calories.	B. t. u.	
							Air dried.	Water free.
6576	Brown, fibrous......	Fremont, N. H......	6.34	7.93	0.63	5,161	9,290	9,920
6722	.....do............	Hamburg, Mich.....	7.50	6.55	.28	5,050	9,090	10,026
6572	Light-brown, fibrous	Rochester, N. H....	11.64	4.06	.22	5,042	9,083	10,280
6191	Dark-brown.........	Westport, Conn.....	12.70	4.12	.24	4,772	8,590	9,839
6580	Brown, structureless	New Durham, N. H.	6.06	17.92	.88	4,415	7,947	8,460
6203	Brown.............	New Fairfield, Conn.	9.63	7.93	.46	4,367	7,861	8,698
6193	Brown, fibrous......	Westport, Conn.....	19.69	3.23	.19	4,273	7,691	9,578
6198	Brown.............	Kent, Conn.........	12.10	7.22	.83	4,269	7,684	8,743
6398	Brown, fibrous.......	Cicero, N. Y........	14.57	7.42	.25	4,209	7,576	8,869
6436	Brown.............	Black Lake, N. Y....	8.68	16.61	.93	4,179	7,522	8,237
6279	Brown, fibrous......	La Martine, Wis....	9.95	16.77	.79	4,149	7,468	8,293
6555	Salt marsh..........	Kittery, Me.........	13.50	12.04	1.94	4,066	7,319	8,462
6571	Black..............	Greenland, N. H....	6.62	24.11	1.01	3,992	7,186	7,695
6290	Light-brown, structureless.	Waupaca, Wis......	6.62	24.44	.65	3,872	6,970	7,465
6278	Brown, fibrous......	Madison, Wis.......	8.99	18.77	.38	3,857	6,943	7,628
6199	Brown, sandy........	Kent, Conn.........	9.06	36.06	1.46	3,291	5,924	5,924
6396	Black..............	——, N. Y.......	6.52	28.50	.57	2,867	5,161	5,521

CHARACTERISTICS DETERMINING FUEL VALUE.

The characteristics determining fuel value have already been indicated in part; the most important are ash and water content, degree of decomposition, density, and color. The effects of ash and water are to lower the heating value nearly in proportion to the amounts in which they are present. In general, also, it may be said that peat that is coarse in texture and fibrous or woody in structure is less valuable for fuel than the finer-grained types which are compact and dark colored when dry. This is readily demonstrated by comparing the theoretical heating value in the series of peat analyses given on page 53, and is due in some degree to the concentration of the fuel element carbon as the original chemical compounds of the peat become more and more completely broken up.

The ideal fuel should maintain a steady and efficient fire, and be capable of easy control, with small attention and without developing smoke or offensive and injurious gases. It must not have too much ash and must not produce clinkers and slag that will clog the fuel bed and fuse to the grate bars or fire box, nor give off compounds that corrode the boiler or other metal work with which they come in contact. In addition, it must be cheap, efficient, and transportable.

Natural gas is the nearest approach to this ideal occuring in nature, and where it has been found has proven to be the best fuel known.

COMPARATIVE FUEL VALUE OF PEAT IN DIFFERING CONDITIONS.

FRESHLY DUG.

Freshly dug peat from an undrained deposit consists of from 85 to 90 or even 95 per cent of water, 8 to 13 or even as little as 3 per cent of carbonaceous materials, and a widely variable percentage of incombustible matter or ash. Freshly dug, wet peat, therefore, has such small heating value that it can not be made to burn until it is at least partly dry, reaching its highest value as a fuel only when the water has entirely disappeared. Peat with enough water present to feel wet to the touch will burn in a strong draft, but the intensity of the heat as indicated by the temperature is low compared with that of the perfectly dry substance, because most of the heat developed by the combustion is rendered latent in evaporating water from the particles of peat near those that are burning.

DRIED.

The maximum temperature developed by the combustion of perfectly dry peat of good quality under the most suitable conditions of draft and combustion chamber is very high, being over 4,000° F. (2,200 ° C.). This temperature is lowered by the presence of even small amounts of water or by ash, hence the desirability of having the peat as dry as possible when the highest temperatures attainable by its use are necessary. The drying of peat that is to be stored before

use, with the hope of increasing its efficiency below the "air-dry" stage of 12 or 15 per cent to 25 per cent moisture content, is useless and a needless expense; if so dried, it soon reabsorbs water from the air, just as wood and other vegetable matter do when kiln dried.

The water content of air-dry peat varies considerably in a given locality according to the season, and in different parts of the country, on account of variations in the relative humidity of the air, there will be an even wider variation, the water content of air-dry peat being constantly higher in the moist and cool regions, where there is a high relative humidity, than in the drier and warmer ones. The lower limit of moisture in the central United States will probably be at least 8 per cent; the highest limit will probably be along the coast of New England, where it is not far from 25 per cent, or about that of the European countries.

EFFECT OF EXPOSURE TO AIR.

The weight of a cubic foot of the heavier and denser qualities of peat, when freshly cut from undrained beds, may be as much as 70 or 75 pounds to the cubic foot, but after a few days of exposure to the air its water content will be reduced by at least one-half of its original amount. Continued drying in the sun and wind will finally lower it to from 8 to 25 per cent of the weight of the mass, within which limits it remains permanently, as indicated in the preceding paragraph.

Accompanying the loss of water there is a great shrinkage in bulk, and the block may be reduced to a fourth of its original volume in drying. The weight of a full cubic foot of air-dry cut peat ranges from about 10 pounds for very light kinds to over 60 pounds for the black, thoroughly decomposed kinds.

CONDITIONS OF IGNITION.

The lighter, more fibrous kinds of peat ignite when heated in the air at about 400° F. (200° C.) and burn with a red, smoky flame. The burning is accompanied by a characteristic biting or acrid odor and grayish or whitish smoke, arising from the destructive gasification of the poorly carbonized organic matter of which the peat is composed.

Black, pitchy or denser kinds of peat do not ignite as readily, burn less rapidly, and often need a higher temperature to induce combustion than do the other types. This is so well recognized in European countries where peat is used that a supply of the light, fibrous material from the top of the peat beds is always cut for use as kindling and for starting quick fires; the denser kinds from the deeper parts of the deposit are used for general purposes.

CHARACTER AND EFFECT OF ASH.

Unless a peat has a high per cent of ash, the quantity resulting from burning it is small. In any case, the ash is light in weight and pow-

dery in texture and generally does not fuse into clinkers or slag, even in a strong fire. When the surface of a peat fire is covered by ashes, or the draft is cut off, the fire smolders as long as there is any unconsumed peat left, and may be rekindled at any time by renewing the supply of air. The relatively large amount of oxygen present in the fuel itself probably supports combustion under these circumstances, some of it being liberated from the fuel by the heat. This may also account for the fact that peat fires require less draft than those of other fuels.

AIR-DRIED PEAT COMPARED WITH COAL.

According to European authorities, the heating value of air-dried cut peat is small as compared with that of coal, being only a little more than one-half as much; expressed more definitely, it ranges from five-eights to five-ninths as much, or in the ratio of 1:1.6 or 1:1.8. Reference to the tables of analyses (pp. 186 to 203) will show that the fuel value of the United States peats has a comparatively high range. To obtain the same evaporating effect, from 8 to 10 or even as much as 18 times the volume of peat in the crude, air-dry state must be used as of good coal. It is necessary, therefore, to provide plenty of room for transporting, storing, and firing if the fuel is used in this form.

The deficiencies of peat thus prepared were recognized at an early stage in its use for power production, and several methods and many machines have been devised for compacting it, thereby increasing its efficiency and lasting qualities as fuel, and making it more easily transported and stored.

In spite of its manifest disadvantages in the more bulky and crudely prepared forms, such as hand-cut, air-dried sods or blocks, peat in compacted forms is well liked by those who have used it. It is reported to be an admirably adapted fuel for all domestic purposes, as it is easily kindled, burns freely when the drafts are open, yields a quickly developed and intense heat, is light and easily handled, and is very clean, giving neither soot, dust, nor any other form of dirt. Fires fed with it are easy to keep, regulate, and control, and quickly produce enough heat at all times for any special purpose. When used in heating stoves and furnaces it also gives satisfaction, furnishing a mild but sufficient heat, although success with it for these purposes depends seemingly as much on the experience and judgment of the individual who has charge of the fire, the way in which it is handled, and the kind of grate and fire box used as on the fuel itself.

USE OF PEAT FUEL IN EUROPE.

In European countries where peat is used largely for domestic fuel special stoves for it have been designed and sold, although these do

not appear to have any very general use, as the common report made by those who have investigated the matter is that the peat is usually burned in the same stoves as other fuels. The best results from using peat would probably be had by more frequent firing, with less draft and smaller grate openings, and for power generation by having larger and longer fire boxes than are used with coal. For open grates peat is an ideal fuel, and for this purpose alone it should command a large sale, as it is in many respects superior to wood and coal.

EFFICIENCY OF PEAT FUEL FOR STEAM GENERATION.

The efficiency of this fuel in comparison with others is at once questioned when its use for the generation of steam under boilers in manufacturing establishments and power and lighting plants is proposed. If trial by the owners of such establishments demonstrates that the same money spent for any other fuel will give a larger quantity of steam, or more heat units than will peat, or will insure a more readily obtained and certain supply or even one more in favor with the men who handle it, the probabilities are that the other fuels will be given preference and used exclusively. For these reasons peat-fuel manufacturers will have to make the best possible showing by producing a fuel that is cheaper and more convenient to use and very efficient as compared with types already on the market. They must also be able to provide an abundant and steady supply the year round if they expect it to be generally used for power purposes, as it must be if large investments in peat fuel are to be profitable.

CALORIFIC VALUE OF PEAT FUEL.

Taking up briefly the calorific value of peat fuel, the tables below should be examined carefully, as they enable a comparison of the value of peat prepared in several commercial ways to be made with that of other kinds of fuel in common use.

It should be remembered in this connection, however, that unless the peat is heated enough to drive off some of the volatile matter, thereby increasing the proportion of carbon present, the theoretical heating value—that is, the number of heat units per pound—is practically the same whether the peat is cut, pressed, or briquetted. When artificial heating is resorted to and carried on at sufficiently high temperatures to partly char the peat previous to or during briquetting, or when a bituminous or resinous binder is used in the process of making the briquets, the calorific value may be much increased. However, in the first case there is a loss of weight of the material proportionate to the gain in fuel value, and in the second the binder may furnish the additional heat units at a high cost. Probably

both factors must be considered to account for the differences which are apparent in the following table: [a]

Calorific values of peat and other fuels.

Kind of fuel.	Calorific value per pound.	Kind of fuel.	Calorific value per pound.
	B. t. u.		*B. t. u.*
Wood..................................	5,760	Peat coke..............................	12,676
Air-dried cut peat......................	6,840	Semibituminous coal...................	13,000
Pressed peat...........................	7,290	Peat briquets..........................	13,330
Bituminous coal.......................	11,000	Charcoal..............................	13,840
Gas coke..............................	12,060	Anthracite............................	14,600

The following analyses are of peat from the same part of a deposit and were made independently; the calorific value is on the ash-and-moisture-free basis.[b]

Calorific value of peat prepared in different ways.

Lab. No.	Character of peat and method of preparation.	Calorific value per pound.
		B. t. u.
6436	Air-dried cut peat...	10,067
6394	Air-dried machine peat..	9,970
6392	Steam-dried machine peat..	9,877
6395	Steam-dried, powdered, and briquetted peat.........................	10,111

The slight variations obtained in the determinations probably are due to differences in the quantity of ash present, this varying more than 1 per cent in the different samples, as is very often the case in different collections of the same material. The analyses show conclusively that the untreated peat analyzed has almost exactly the same theoretical heating value as that which has been dried by steam heat and briquetted without binder or heat in an open-mold briquetting press.

CONCLUSIONS.

The foregoing indicates that briquetting alone does not increase the heating value of a given weight of peat, but, as is shown below, it does give more heat units for a given volume, and therefore improves the efficiency of the fuel for commercial uses.

The effects of the presence of ash and moisture on the calorific value of peat have already been discussed. Of more importance still are the tables of analyses given on page 53, since they were all made by the United States Geological Survey, and show the calorific value of the fuels cited in their commercial condition.

These tables clearly demonstrate that peat is a better fuel than wood or the lignites with which it is compared, and at its best is not

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a Ann. Rept. Michigan Geol. Survey, 1907, p. 334.   *b* Analyses by U. S. Geol. Survey.

much inferior to some grades of commercially important coals, although generally considerably poorer. The best peat has about 75 per cent of the heating value of anthracites and about 80 per cent of that of the Illinois coals, or from 85 to nearly 90 per cent of that of the Rhode Island and Wyoming samples; the poorest of the peats with high ash and moisture content are only about half as valuable as the best of the coals and are commonly rated as 55 to 65 per cent as valuable as the poorest coals. These comparisons are made on a strictly commercial basis, the peat being air dried and the other fuels in the state in which they were received from the mines.

The following table shows the effect of the moisture and ash on good and poor peats:

Comparative calorific value of peat with various amounts of ash and water.

Ash.	Water.	Calorific value per pound.	Ash.	Water.	Calorific value per pound.
Per cent.	*Per cent.*	*B. t. u.*	*Per cent.*	*Per cent.*	*B. t. u.*
Free.	Free.	10,726	10	Free.	9,653
4	Free.	10,297	20	Free.	8,581
4	11	9,117	10	15	8,045
4	15	8,688	10	20	7,508
4	25	7,615	20	15	6,973
4	30	7,079	20	20	6,436
4	50	4,934			

The statement should be emphasized that peat which has been dried below the air-dry condition, but not charred, will soon absorb moisture enough from the air to give it about the amount of water which it would have had if air dried at first. The percentage of water thus hygroscopically absorbed from the air is less for very dense black peat than for the more fibrous brown kinds, but to continue the drying of any type lower than about 15 per cent, with the expectation that it will remain fixed there, is useless. Peat thus dried below the critical percentage of moisture to secure greater efficiency for special purposes must therefore be used immediately if any advantage is to be gained by the operation; storage, even for a short time, permits water to be reabsorbed from the air.

If the peat is heated sufficiently to carbonize or char it, as may be done by artificial drying at high temperatures, it loses to a large degree its property of absorbing moisture from the air.

CHEMICAL EFFECTS OF ARTIFICIAL DRYING.

The commonly used method of drying peat for fuel is by exposure to the air, either in the sunshine or under shelter, but as this process, on account of changeable weather conditions, is a slow and somewhat uncertain way of getting results, many artificial drying systems have been proposed or actually tried. At this point in the dis-

cussion, however, the chemical effects are to be considered rather than the processes of drying.

There seems to be a slight chemical change in peat that is dried in the air without heat owing, in part at least, to the contact of the oxygen of the air with the peat as it is drying. The most obvious evidence of change is the blackening of the peat while it is still wet, especially after it has been thoroughly macerated; the discoloration often begins as soon as the peat is cut. Whether there is any change in weight accompanying the change of color from brown to black has not been determined.

Various observers have noted that peat loses in weight when heated at about the boiling point of water, and some have supposed this loss to be due in part to the distillation of combustible gases. It seems more probable, however, that a part of the chemically combined water of the complicated compounds making up the peat is driven off at these lower temperatures and that little if any combustible gas escapes.

Bornstein[a] reports that brown peat with 17 per cent of water, when distilled in a retort closed at one end, gave water at 100° C. (212° F.), gas at 250° C. (482° F.), tar at 325° C. (617° F.), and combustible gases at 400° C. (752° F.).

If the material used was representative, little gaseous matter of value is driven off from peat until heating is carried well above the boiling point of water. The elimination of incombustible gases at about 500° F. and the use of higher temperatures for drying, although reducing the weight of the substance to some extent, should undoubtedly increase the calorific value by so much as the carbon is increased in proportion to the other constituents. Clearly, therefore, artificial drying may decrease the weight of the peat treated, but it will also increase the fuel value. The latter cause, as noted above, operates to give the high fuel value to peat briquetted after artificial drying.

PRACTICAL OR ECONOMIC CALORIFIC VALUE AND EVAPORATIVE EFFECT OF PEAT.

The economic calorific effect of a fuel used under most favorable circumstances in practice may be expressed in the number of units of weight of water that can be raised from the freezing to the boiling point of water and converted into steam by the heat developed by the combustion of a single corresponding unit of the given fuel. The units of weight used are the gram (or kilogram) or the pound, according as the metric or the English system of weights prevails. The practical calorific value of any fuel is manifestly to be derived from the previously ascertained theoretical heating value stated in

thermal units, if the number of these units required to convert a unit weight of water at the boiling point into steam of the same temperature be known. This value has been found to be 536 calories, and as the number of heat units required to raise a given body of water from the freezing to the boiling point under normal atmospheric pressure is practically always the same (100 calories or 180 B. t. u.), the evaporative effect of a pound of peat may be ascertained by dividing its heating value stated in calories by 536, or, if stated in British thermal units, by 965. The result will be the number of pounds of water that the combustion of a pound of peat will convert into steam after the boiling point is reached. This amount will be reduced, however, by the number of heat units lost in raising the temperature of the water to the boiling point; it will also be reduced through the inefficiency of the boilers used. In practice the reduction will vary from a fourth to a third of the whole as determined above, so that the practical calorific value expressed in pounds may be from two-thirds to three-quarters the evaporative effect.

The following table cited from Ryan[a] shows the comparative economic calorific value of several types of fuel:

Average economic heating effects of ordinary fuels of European origin.

Kind of fuel.	Quantity of water evaporated per pound of fuel.	Kind of fuel.	Quantity of water evaporated per pound of fuel.
	Pounds.		*Pounds.*
Coal	6.5	Peat	3.5
Lignite	4.5	Machine peat	4.8
Wood	3.5		

Lyons[b] gives the theoretical evaporative effect of Indiana peat, as compared with coal from the same State, as follows:

Evaporative effect of Indiana peat and coal.

	Number of samples analyzed.	Evaporative effect (pounds of water per pound of fuel).		
		Maximum.	Minimum.	Average.
Coal	20	13.4	12.1	12.8
Peat	29	10.8	4.7	8.0

The following table has been compiled from fuel tests made by the United States Geological Survey[c] at St. Louis, Mo. The data were

a Ryan, H., Econ. Proc. Royal Dublin Soc., vol. 1, pt. 13, 1906, p. 468.
b Lyons, R. E., Thirty-first Ann. Rept. Ind. Dept. Geology and Nat. Hist., 1906, p. 102.
c U. S. Geol. Survey Bull. No. 332,

obtained from actual boiler tests, and the number of pounds of water evaporated at 212° F. per pound of fuel used was calculated separately for each test.

Fuel tests made by the United States Geological Survey at St. Louis, 1906–7.

Test No.	Source of fuel.	Type of fuel.	Pounds of water evaporated at 212° F., per pound of—		Percentage of water in fuel as fired.
			Dry fuel used.	Fuel as fired.	
386	Florida............	Compressed or machine peat.........	6.04	5.00	17.21
410	Alabama..........	Bituminous coal....................	9.00	8.69	3.43
294	Arkansas..........	.....do............................	8.84	8.35	5.55
340	.....do...........	Lignite...........................	5.86	3.59	38.75
420	Illinois...........	Bituminous coal....................	8.40	7.67	8.72
432	Indiana...........	.....do............................	8.60	8.02	12.79
311	Kansas...........	.....do............................	7.88	7.23	8.28
462	Kentucky.........	.....do............................	8.61	7.92	8.04
486	Missouri..........	.....do............................	5.66	6.36	4.51
469	Ohio.............	.....do............................	9.28	8.90	4.10
467	Pennsylvania......	.....do............................	10.04	9.65	3.90
510	.....do...........	.....do............................	8.92	8.46	5.15
401	Rhode Island......	Graphitic anthracite...............	4.93	4.81	2.33
291	Texas............	Lignite...........................	6.90	4.40	36.27
476	Virginia..........	Anthracite (pea coal)..............	7.83	7.46	4.73
290	Washington.......	Subbituminous coal................	7.44	6.25	15.96

This comparison includes only a single specimen of peat, used for a comparatively short time, and of necessity prevents the reaching of any general conclusions of value, but the confirmation which it gives to other estimates of the relative value of peat is striking. The coal samples used for the tests were generally run-of-mine, carload lots, shipped under the inspection of the United States Geological Survey, and tested under known conditions.

The table shows that slightly more than 60 per cent as much water per pound was evaporated from the peat as from the best sample of bituminous coal cited, when considered on the water-free basis, and 51.8 per cent as much per pound when compared "as fired." On the other hand, the figures are 90.7 and 75.5 per cent when comparison is made with the poorest of the bituminous coals or, for the average of the 10 samples listed, 70 per cent for the water-free fuels, and 61.5 per cent for the fuels as fired.

The peat gave better results than the graphitic anthracite from Rhode Island, which evaporated only 81.4 per cent as much water on the dry and 96 per cent as much on the "as fired" basis. Compared with the pea-size Virginia anthracite, the peat was 77 per cent as valuable "as fired." The subbituminous coal from Washington evaporated about 20 per cent more water than the peat in each form of statement.

In the case of the lignites, the sample from Texas was 13 per cent better as dry fuel, but its large percentage of moisture reduced its value to 88 per cent of that of the peat as fired; that from Arkansas

had 97 per cent of the value of the peat on the dry basis and about 72 per cent as fired.

The peat used was of good quality, as shown by the accompanying proximate analysis:

Proximate chemical analysis of Florida No. 1 peat.

[Used in steaming test 386.]

Moisture	17. 21
Volatile matter	51. 01
Fixed carbon	24. 85
Ash	6. 93
Sulphur	.49
B. t. u. per pound of dry fuel	10, 082

In a preliminary report[a] of the steaming test with peat on which this discussion is based, the statement is made that "No difficulty was encountered in keeping the boiler up to its rated capacity, and in fact during the four hours' run the percentage of rated horsepower of the boiler developed was 113.2. The amount of peat burned per indicated horsepower hour at the steam engine was 5.66 pounds, and per electrical horsepower hour at the switchboard was 6.98 pounds. The principal difficulty in the utilization of peat under boilers appears to be the frequency with which it must be fired. On account of the lightness of the material and also on account of its rapid combustion the fireman was kept at work almost constantly during the test."

IMPROVEMENTS PROBABLE.

There are strong probabilities that with more experience with peat fuel, and consequent better adjustment of the drafts and slight modification of the fire box, the difficulties mentioned above would have been largely obviated, and at the same time a somewhat smaller consumption of fuel would have been obtained with no material decrease in the efficiency of the boiler. These probabilities are strongly supported by the statements of users of peat who have given it prolonged trial for boiler use; they state that it requires much less draft than coal. A fire of peat is claimed to raise steam in a boiler in about one-half the time taken by a coal fire; the fire is said to be lasting, nearly or quite smokeless and to make a very light, powdery ash, which does not fuse readily, if at all, so that there are no clinkers produced. Further claim is made that no unconsumed fuel is left as cinders either in the fire box or in the ash pit. Because the combustion is complete, no soot is deposited, and by reason of the small percentage of sulphur present in the fresh-water peats, scaling and other forms of corrosion of grate bars, fire box, and boiler are reduced to a minimum; the boiler flues are generally left entirely without any

a U. S. Geol. Survey Bull. No. 290, p. 135. (Now out of print.)

661°—Bull. 16—11——5

form of deposit except, in rather unusual cases, a small quantity of very powdery ash. The lightness of the peat makes it the most easily handled of all solid fuels, and it can be placed on the fire exactly where needed.

ACTION OF VOLATILE HYDROCARBONS.

As has been noted, the volatile hydrocarbons of peat are not driven off as black smoke, as are those of bituminous coal, but are consumed in the fire box above the fuel bed, thus quickly giving a high temperature; by this means steam is generated rapidly and the supply is maintained by the slower combustion of the fixed carbon of the fuel bed. The actual efficiency of peat when properly fired in a well-designed fire box, as compared with the theoretical calorific value, is apparently greater than would be expected, because of its ready ignition, complete combustion, as well as its freedom from cinders, clinkers, sparks, soot, smoke, and deposition of heat-absorbing compounds on the fire box and in the boiler flues. On the other hand, coal yields a large amount of ash and soot, which clog the flues, and corrosive gases, which cover the boiler and any metal surfaces with which they come in contact with a constantly thickening incrustation of rust; a considerable percentage of the good coal fails to burn, and the fusible character of the ash makes slag and clinkers a constant source of annoyance as well as loss of heat. These factors reduce the efficiency of most kinds of coal more than is commonly appreciated, because each lowers the steam-generating power of the fuel and lessens by so much its theoretical superiority over peat in ordinary boiler practice.

Even if the truth of these comparisons were not apparent, some sacrifices of heating value could seemingly be tolerated in view of the smokeless feature of peat combustion as compared with the constantly increasing losses of the public from damage to and defacement of property and probable injury to health directly traceable to the smoke of bituminous coal.

PREPARATION AND MANUFACTURE OF PEAT FUEL.

ESSENTIAL PRELIMINARY CONSIDERATIONS.

The preceding sections of this paper have discussed at length the occurrence and origin of peat and those of its qualities which appear to be of most importance relative to its value as fuel, and which need to be taken into account in making it into a marketable fuel on a large scale.

Before such production can be made commercially successful on any scale, however, other factors than those pertaining solely to the properties of peat and its fitness for specific use must be considered. Some of these are presented here as preliminary to the more technical part of the paper, because the success or failure of all attempts to make any product from peat must be based upon them, and because they are so often overlooked or deliberately ignored by those about to enter upon or promote the manufacture of peat products. The need of such a discussion is emphasized by a glance at the history of the numerous attempts at peat-fuel manufacture that have been made in the United States during the last 50 years. Large sums of money, aggregating many hundreds of thousands of dollars, have been spent upon such ventures, yet practically no financial returns have been received from them by their supporters.

These facts are so well known in some sections of the country where there are numerous peat deposits that a large part of the conservative investing public can no longer be interested in any enterprise based on peat utilization, no matter how attractively it may be presented. This section of the report is designed to show that causes which are avoidable have been chiefly responsible for the losses and failures of peat enterprises of the past—not a lack of desirable qualities existing primarily in the peat itself and in the products made from it.

ERRORS THAT HAVE CAUSED PAST FAILURES.

To state the matter simply, the study of unsuccessful peat-fuel plants in this country, and an analysis of their history, emphasizes the fact that a number of important matters must be taken into account before any peat bog can be made the source of a paying business, even when the peat is of good quality, and can be shown to be

valuable fuel if rightly treated. It seems clearly obvious from such examination that much of the lack of success observed has been due to failure to take such factors into account, to ignorance of their existence, or to too great optimism when they were under consideration.

IGNORANCE AND INEXPERIENCE.

The most important single group of such errors may be charged, perhaps, to ignorance and inexperience. Ignorance is not excusable, however, since there is a very considerable mass of literature in nearly every European language, which details at length records of the theoretical and business experience gained during more than a hundred years of experiments. Although these experimental data have been gathered under economic conditions differing somewhat from those in America, the difference is not so great that the results can not be made applicable here; to entirely overlook or throw them aside is to invite failure when success might almost as easily be attained. For example, much greater progress could be made in a given time by taking the best types of European machinery and processes for manufacturing peat and improving them than by beginning anew and working out similar ones independently. Large sums of money and much disappointment would also be saved.

FAULTY ENGINEERING.

Many of the difficulties which have been encountered in peat utilization in the United States, as well as some of the failures, may be attributed to what may be termed "faulty engineering." Under this head may be grouped mistakes made in choosing sites for the erection of plants; poor planning and erection; unwise selection of the kind of product to be made and the way to make it; the choice of inefficient machinery by which it is to be made; and even in imperfect prospecting, surveying, and proving up peat bogs.

There have also come to the attention of the writer many cases in which certain fundamental business considerations seemingly have been ignored or overlooked, thus predestining the ultimate collapse of the enterprises.

As the results of overlooking or neglecting these factors have been observed in many parts of the country, persons who, without previous experience, are considering investment in some form of peat utilization, may be helped by a brief statement of some of the economic and related principles that must govern the founding and successful growth of any business that has the use of peat as a basis. Attention may in this way be directed to some of the dangers of loss which may be encountered as the result of inexperience.

FACTORS GOVERNING PROFITABLE UTILIZATION OF PEAT DEPOSITS.

MARKET.

One of the first objections which is raised against the use of peat for fuel is the one made by economists and others that the country is already so well supplied with good fuel in other forms, such as wood, coal, oil, and gas, that there will be no sale for peat; they contend, a priori, that there will be no market for peat fuel; hence investigation of its possibilities is useless. The market is rightly considered to be the most important factor and the one upon which the fate of any peat development must hinge, for unless the product of an industry finds a ready sale at prices which will meet all costs, maintain the the plant, and give a profit on the capital invested, there can be no permanence to it—in fact, no industry.

At first thought, any desirable type of fuel, would seemingly find a ready sale at good prices, but more careful consideration will raise the question as to whether a substance like peat, which is quite unknown and untried in most American fuel markets, will be accepted by any number of buyers until they have learned by experience that it may be depended upon. Experience shows that most people are conservative in adopting new materials in place of those which they have long known and have found satisfactory. The conclusion may be drawn, therefore, that the market for any form of peat, as for other new materials, must generally be won by slow and persistent effort, in which a first-rate product, skillful manufacture, careful advertising, and constant demonstration must be combined.

The important markets for fuel are located in the larger towns and cities; hence a peat-fuel factory should be situated where one or more large centers of population and manufacture can be worked up for a market. It must be remembered, however, that the fuel trade in such places is thoroughly and closely organized, and therefore opposition must be expected to any new and independent product. This opposition, if effective, will result in reduced sales, in lower prices, and obviously in smaller profits during the stage while competition from these agencies is active.

A good market, then, generally must be built up. Not less than five years after peat fuel is put on a given market would probably be needed for it to find its proper place among other fuels. At the end of the period peat could hardly be expected to form more than 10 per cent of the entire quantity of fuel used for all purposes in the region surrounding the proposed plant.

Conversely, time is needed in all new manufacturing enterprises to get the plant to a stage where its efficiency permits other than slow and expensive production. This period of development ought to be

the time when a market is being secured and established so that the product as fast as it can be made will be taken at fair prices, and so that as soon as a full and satisfactory output is attained the whole of it can be sold with profit.

So far as can be seen at present, or can be judged from European experience, it will not be feasible to send peat fuel long distances by rail. Indeed, the closer to a good market that it can be produced, the more certain will be the chances of success. The abundance and prices of other kinds of fuel, the means of transportation, the attitude of the transportation companies, the conservatism of the population, and the way in which the peat is prepared will all be factors in determining the maximum distance that can be reached by a given peat-fuel factory. This maximum distance will presumably be less than 50 miles for a long time after the factory has reached a productive stage.

The market within this radius can be secured only by making a uniform product with enough good qualities to displace fuels which have been known long before the time of its introduction. The peat must be fairly and honestly shown to be really desirable, and the more honestly the demonstration is made the more profitable will be the final outcome.

TRANSPORTATION FACILITIES.

It will probably not be possible for a long time in the future to utilize as a source of fuel peat bogs that are unfavorably located in respect to lines of railroad already built, or to water routes, such as rivers, lakes, and canals. The possible exception lies in bogs which may be utilized by producer-gas plants where the peat is converted into electric energy at the bog, or into fuel gas that may be conveyed by pipe lines to the places where it is to be used. Both of these uses are quite practicable, but are likely to be slowly developed, because of the conservatism of capital in taking up entirely new lines of investment.

It is important, therefore, to be assured that good transportation lines to the site chosen for a peat-fuel plant are already in existence, or will be before the plant is built. The cost of every item is so much increased where teaming is necessary, that, except on a very small scale, a plant can not be established and brought to a successful production with this sort of transportation. The limit to which the finished peat fuel can be drawn by horses and sold at a profit is easily determined when the cost of production is added to other charges, including the cost of men and teams, and subtracted from the selling price. Failure to secure steam or water transportation to the factory has obviously been the cause of failure of a very considerable number of peat-fuel plants, either before they were fully developed or soon afterwards.

LOCATION.

Closely connected with the factors which have been mentioned is that of choice of location of a bog on which to establish peat operations. Too much importance can scarcely be attached to this, as the success of the enterprise depends not so much upon the quantity of peat to be manufactured as upon the cost of production and marketing as compared with the price at which sales can be made. Clearly, therefore, a small, favorably located bog is preferable for experimental exploitation to a large one remote from market, transportation lines, and cheap labor. supply.

The margin of profit on the finished product of any type of peatfuel plant will be so small, because of the low price at which it must be sold in competition with coal and wood, that no extra charges should be placed on its production by a choice of location that will entail a high cost for labor and maintenance, and slow, uncertain, and expensive transportation to market. The greed that urges the promotors of projected enterprises to get the largest possible quantity of raw material may blind them to the handicaps caused by its location, and thus bring the entire investment to a disastrous end.

AVAILABLE CAPITAL AND QUANTITY OF PEAT.

An estimate of the life of the plant, its size, and consequently the amount of money invested, must be determined by the total quantity of good peat in the bog selected for exploitation; hence an approximately accurate knowledge of how much peat can be had is essential before other plans are made, especially if the deposit is of small area and depth. If it is very large, the need of care in this respect is not so great as when the quantity is clearly limited; in all cases, however, sufficiently exact tests should be made to insure the fact that the projected investment is justified by the quantity of good raw material available.

The prosperity of the enterprise and the returns from the investment will depend upon the salability of the output and the reputation which it wins among fuel consumers. These, in turn, must be based upon the quality of the peat, its fuel value, structure, ash content, and the kind of fuel that it makes. In considerable measure, also, some of these factors control the cost of production, because upon them depends the ease and consequent cheapness with which the peat can be dug and made ready for market.

PRACTICAL METHOD OF COMPUTATION.

The quantity of peat in a given deposit may be determined with sufficient accuracy for practical purposes by finding its total area

and average depth, and assuming that at least 200 tons of air-dry machine peat can be made per acre for each foot in depth. Some heavy types of peat will yield more than this, and the figure is seemingly conservative for American peats, which in practice generally give a dense, heavy product.

So many erroneous ideas have been expressed as to the lower limit of size of bogs that may be used for making peat fuel that the following illustration is cited to show that in Europe bogs of small size are used even where considerable investments are made. At Skabersjö, Sweden, a producer-gas plant equipped for generating electricity, and costing several thousands of dollars, has been erected at a peat deposit 37 acres in area and averaging 5 feet deep. The life of the plant is estimated at 30 years at the present rate of consumption of fuel, of which there is estimated to be 44,500 tons available. There are other bogs in the neighborhood which may be used after the one now in use is exhausted, but none is of great size. The plant develops 300 horsepower.

The illustration mentioned indicates that small deposits of peat of small average depth will justify exploitation if the plans formed are not too ambitious, as the annual production of 1,000 or 1,500 tons of peat fuel can be assured for a long period of years from such bogs as the one cited. Such a quantity may be sufficient to furnish all that will be taken by a good-sized community for several years after a plant is built. It should also be taken into account that a number of years would probably elapse before so large an output could be made by the plant or be taken by local markets.

There are many small towns in the northern United States near which are sufficiently large beds of peat to supply electric current for many years for lighting and other uses. Likewise, power for factories and mines—where now the fuel used is coal shipped by rail from distant mines—might be cheaply obtained from near-by peat beds.

The physical properties of the peat beds under consideration should be such that the raw material may be easily dug and easily and rapidly put into the desired form of product with the chosen machinery. If condensed or machine peat to be shipped from bog to market by rail is the product decided upon, the peat should not be very fibrous or woody. These qualities, however, do not reduce its value so much for local use, except as stumps and other remains of trees increase the cost of digging, which in most cases will be small per ton of final product.

METHODS OF PROSPECTING PEAT BOGS AND ESTIMATING THEIR CONTENTS.

Peat beds of large area and considerable average depth are rather rare in the United States, and where they do occur are often so located with respect to lines of transportation or to markets that they could not be used at present except for the production of gas for power generation. Bogs of this class need little careful prospecting, as the quantity of peat in them is very large, and ordinary errors in the relation of the estimated quantity to that actually present may be disregarded when a quantity of material sufficient to warrant exploitation is known to be present.

There is greater need of carefully testing bogs of small area, and the cost of doing this is relatively small. After the area has been found by an ordinary land survey, a series of parallel, uniformly spaced lines should be laid out at right angles to the long axis of the bog and entirely across its surface. Along the lines test holes to the bottom of the deposit should be made to determine its variations in depth. The intervals between the holes should be of the same length, and in final proving up should be dug as deep as possible with a spade or post-hole digger. An earth auger with an open spiral or a ship auger of similar construction may be welded to a section of half-inch gas pipe, and used for sounding the depth and for taking from below the surface samples for chemical analysis. If the tool is to be used often, 3 or 4 foot lengths of pipe, provided at one end with a carefully fitted coupling and at the other with a thread which fits the coupling, will be found convenient. The coupling may be fastened to the pipe by a pin which prevents its unscrewing from that piece when another section is joined to it.

The chief objection to the use of the auger lies in the fact that in deep deposits the sample taken at a considerable depth may be stripped from the auger as it is drawn up and may be replaced by the material through which it is drawn, so that the origin of the sample may be doubtful.

A much more exact tool is one devised by the author and used by him with great satisfaction for several seasons. The essential part of this tool is a stout brass tube about a foot long and seven-eighths of an inch in inside diameter. The lower edge of the tube is sharpened, and inside the upper end is closely fitted and riveted a shoulder or ring of brass one-sixteenth of an inch thick to serve as a stop for the piston and catch. Inside the cylinder is a brass piston of three-fourths inch rod accurately fitting the opening in the upper part of the tube and bushed out at the lower end by a ring of brass to fit the cylinder. This lower end of the piston is slotted on one side, and in the slot is fastened a brass spring catch which automatically locks

when the piston is drawn up and out of the cylinder. A metal peg driven through a hole in the piston at the proper distance from its upper end and at right angles to its long axis prevents its being pushed out of the cylinder at the outlet end. The whole tool can be quickly and firmly fastened to a rod of gas pipe by a screw thread in the upper end of the piston. When used, this tool is pushed down into the peat the required distance, with the plunger filling the cylinder. A sample is taken by drawing up the rod and the attached piston until the catch is heard to lock at the top of the cylinder, after which the cylinder is pushed down into the peat about its own length. This action fills it unless the peat is very wet or very hard. After it is full it may be drawn to the surface without danger of loss.or of mixing with the overlying material. The inclosed sample may then be pushed from the cylinder by unlocking and pushing in the piston. By using this tool carefully and thoroughly the depth and character of any peat bed may be accurately learned with a relatively small expenditure of time and labor. Only by digging with a shovel, however, can be had the large-sized samples that ought to be used in final tests. The large samples are more satisfactory for examination and may give more characteristic results than those taken with the testing tool described.

BOGS LYING BELOW THE GROUND-WATER LEVEL OR CONTAINING MARL.

Small and medium sized bogs which fill deep depressions below the ground-water level, like lake basins, may be expected to have open water or a layer of very watery peat below the thick, firm turf that forms the upper 3 or 4 feet of the bog upon which large trees may grow. Where such watery deposits occur they must be examined with unusual care, because the amount of water may occupy so much of the basin that the peat could not be worked profitably. In one such basin in Michigan, where the turf supported a growth of trees and was so strong that a railroad was built upon it entirely across the basin, more than 60,000 cubic yards of earth were used to give the track stability after the traffic had become so heavy that the turf would no longer support the weight of the grade, tracks, and train. Manifestly, this bulk of earth would fill only a small part of the space occupied by water and watery peat in that basin which hasty or inefficient testing would have determined to be filled with compact peat.

The possible occurrence of marl should also be watched for in basins the upper levels of which have good peat beds. This precaution should be taken especially in those parts of Wisconsin, Michigan, Iowa, Illinois, and Indiana, where the ground water, as shown by its hardness, contains much lime and where marl deposits are of frequent occurrence. Such deposits are often covered with peat to the depth of several feet and may also be interbedded with it. If an auger or

ordinary sounding rod is used in testing such deposits the marl may not be found because, as indicated above, the peat of the top strata may replace it in the auger and lead to the conclusion that the entire deposit is of peat and that a much larger quantity is available than really exists. Beds of soft, fine clay underlying peat in basins may be equally deceptive.

APPROXIMATE DETERMINATION OF PRODUCTIVENESS.

If a close approximation of the actual quantity of air-dried machine peat which a bog contains is desired, a considerable number ·of measured cubic yards should be dug from different parts of the deposit and from different depths and each of these macerated separately. After thorough drying by exposure to the air for some weeks the resulting blocks should be weighed; the average of the series will give the number of pounds of marketable material per cubic yard, and this multiplied into the number of cubic yards in the entire deposit and reduced to tons will give approximately the total weight of the entire available mass of peat. The more thoroughly the sample cubic yards are distributed over the entire area and depth of the bog, the more valuable the data obtained will be. In making estimates and the tests upon which they are based, the turf and the poorly decomposed top stratum of peat for a foot, more or less, below the surface is not usually included.

It is perhaps worth while to point out here the urgent necessity of having all surveying and testing work done thoroughly and by competent men, as money expended on these determinations gives information without which it is impossible to proceed with any certainty to the making of investments; lack of knowledge or a wrong estimate may lead to overconfidence and serious financial loss, or to entire failure.

CHEMICAL TESTS.

The use and kinds of chemical tests have already been discussed, but for persons who may wish to know how to make preliminary examinations of peat for themselves the following directions are given. The recommendation is made that any preliminary tests be confirmed before the peat is utilized for commercial purposes. Analyses by a competent chemist who has the proper apparatus and laboratory equipment to do the work accurately and inexpensively are the most satisfactory.

The equipment needed for such preliminary tests as need to be made are: (1) Some form of weighing apparatus that will give a reasonable degree of accuracy. If the scale is not sensitive, a large sample of peat must be tested. (2) Some form of metal or earthen vessel in which the peat can be weighed and burned. For this purpose a small

pressed metal cup will answer. Before using, it should be thoroughly heated to burn or melt off any substances that would later be lost in this way. (3) A stove or burner in which a clear, smokeless fire can be kept up; a gas stove is ideal for the purpose. (4) Metal tongs or forceps for use in handling the cup when it is hot.

The testing of peat as fuel begins with the air-dried material, although if the quantity of water the peat contains in the bog is desired, this can be ascertained by taking a sample just as it is dug and keeping it in a tightly closed glass fruit jar until the desired tests can be made.

To find the percentage of water in the peat, a sample is removed from the storage jar to the clean, dry cup, which should be weighed as accurately as possible beforehand and the weight recorded. The combined weight of the sample and cup is next ascertained and the weight of the peat obtained by difference. The cup containing the sample may then be placed on a hot steam radiator or in the top of a vessel of boiling water and dried until there is no longer loss of weight after repeated weighings. The difference between the original weight and the last is the amount of water evaporated. By the same method, the percentage of water in an air-dried sample can be found, the drying being hastened by thoroughly pulverizing the peat before it is weighed. In drying samples in these operations care must be taken not to heat the peat much above the boiling point of water on account of the ease with which some of the volatile matter is driven off, causing too great a loss of weight.

After the water is all driven off (a state indicated by no loss of weight when the sample is reheated) and after the weight of the sample is correctly noted, the residue should be set on fire and carefully burned, stirring with a clean wire being resorted to to make combustion complete. When the ash is nearly white, and no unconsumed particles can be seen, the dish should be allowed to stand till cold and the ash and dish weighed. The weight of the dish subtracted from the weight of the ash and the dish is the weight of the ash. Peat with less than 5 per cent of ash is rated as good for fuel; that with from 5 to 10 per cent, medium good; and that with more than 20 per cent is generally considered too high in ash to be of any value for commercial exploitation, except for use in a good gas producer or in some local manufacturing enterprise.

If it is desired to know the quantity of coke that a given peat sample will yield, the sample should be weighed in a cup with a loosely fitting cover, and the cup and sample placed in a flame or a clear fire and heated to redness until gas ceases to come off. The gas will take fire around the cover, and as long as it burns the heating should be continued. As soon as the gas is all driven off, the cup, tightly covered, should be cooled and weighed again. The difference in weight is the

weight of the volatile matter, including the water in the peat, and the residue is the coke, which is the fixed carbon plus the ash.

The density of a given peat may be determined by cutting out a block of such shape that it can be exactly measured and comparing its weight with that of the same number of cubic inches of water. If the block is made to contain an exact number of cubic inches, the operation will be easier. A cubic inch of water at 60° F., the ordinary temperature of the air at which weighings are made, weighs 252½ grains.

In most large cities cheap laboratory appliances can be bought, and these will serve for making the required tests. In the same cities, too, will be found commercial testing laboratories where satisfactory fuel-testing work is done at reasonable rates. Practically all of the educational institutions with courses in mechanical engineering or technical chemistry also have good equipment for making fuel analyses. The essential elements to be obtained for comparison are the ash content and the theoretical fuel value expressed in calories or in British thermal units (B. t. u.).

MECHANICAL TESTS.

According to observation and experience an examination into the mechanical structure and qualities of peat is of more value than a chemical analysis. This is especially true when the material has been selected for a single specialized use requiring a large outlay of money for a properly equipped plant. The importance of carefully investigating the deficiencies of peat, as well as its good qualities for the intended use, is emphasized and should not be overlooked. The defects, the cost and difficulty of handling, the large percentage of water and waste matter as compared with that of usable material, and other qualities of similar nature must be investigated. The more specific the proposed use the more thorough and complete should be the preliminary investigations. As a part of such tests the selected machinery should be tried under conditions as nearly as possible like those of the factory, with large samples of the chosen peat. The samples should be of not less than a ton in weight and of larger size when they can be had, and the tests should be made before any plans for installation of a permanent nature are developed.

Samples used in such tests should be carefully collected, so that they include material from well-separated parts of the bog and from as deep below the surface as the peat can be reached with the usual tools for digging. The costs of these tests may seem excessive, but in the end are justified by the results obtained, whether satisfactory or not. If the peat thus tested turns out to be unsuited for the purposes for which it was chosen, the expense is especially justified.

When such tests are made it is probably more satisfactory to send the material to the factory of the makers of the machinery, where installation is complete and skilled labor is available, rather than to try to set up the machinery temporarily at the bog; by the former course more valuable results will be obtained at much less cost. The tests should be made under the inspection of some competent and disinterested observer who is retained to guard the rights of both parties concerned.

The great importance of thus trying machinery and peat together before erection of the plant has been fully demonstrated in this country. In at least two instances more than $100,000 have been spent in the development of elaborate peat-fuel plants which were never successfully operated. The reason for their failure was that the machinery which had been installed could not manufacture the peat available into the desired product or any other that could be sold at a profit in accessible markets. Other examples less impressive might easily be cited in which lack of success seems clearly referable to the omission of thorough preliminary testing.

SOURCE AND PERCENTAGE OF ASH.

Peat containing a large quantity of ash is not as good fuel as that containing a less percentage, because the former type gives less heat for a given unit of weight. The ash of peat deposits, as noted above, is derived from the mineral matter gathered by the growing plants that have built up the peat. Mineral matter may also be brought in by the water by which the plant remains have been protected and preserved from decay, or may be blown in by the winds. The mineral matter derived from the water is carried either in solution or in suspension and may reach the peat continually with the water or be supplied intermittently by overflow from the ocean tides, lakes, streams, rain rills, or springs.

When peat deposits are being tested those in which the peat is grayish or greenish, or contains whitish or red streaks and spots when dry, or shows shining specks of mica, or is gritty when ground between the teeth, may be classed as of poor quality for fuel unless their analyses prove otherwise. In such deposits the ash content is generally found to be high.

Peat beds that lie in salt marshes, in the flood plains of brooks and rivers, in deltas of streams, or on terraces or slopes watered by springs whose waters are perceptibly mineralized, seldom pay for testing unless in a region where all kinds of fuel are scarce. All of these types of peat beds are certain to be somewhat deteriorated by mineral matter; hence the peat has its fuel value and its possible market value lowered by the presence of too much ash.

In certain parts of the country peat beds in basins, even when no important streams enter them, are sometimes found to be rich in ash. This condition is caused by the presence of plants that concentrate in their cells or tissues or on their leaves and stems some of the minerals brought in by springs or other sources of water supply. The minerals are left on the bottom with other débris at the end of the cycle of growth of the plants. Calcium, magnesium, silicon, and iron compounds are thus segregated from lake waters and become part of the ash of peat.

The effects of the action of waves and currents on sandy or muddy lake shores also must be considered as a source of mineral matter in peat beds exposed to the wash of these sediment-transporting agents. Consequently peat on the banks of lakes having wide stretches of exposed sandy and muddy shores must be tested very thoroughly before using it for commercial purposes.

On the wind-swept plains of the States west of the Mississippi much fine mineral matter in the form of dust is blown into low places, where it is left and becomes a part of any peat deposit which may exist there. The supply of wind-blown dust is fairly constant from year to year, and doubtless the peat beds of Iowa, the Dakotas, and of western Minnesota will be found to have a high percentage of ash, a considerable part of which may be traced to dust.

PREPARATION OF THE BOG FOR USE.

In making the preliminary examination of a bog the quantity and kind of vegetation on the surface of the deposit should be carefully noted. If trees and shrubs are present, their kind, size, and relative abundance should be observed. The presence and frequency of roots, stumps, and buried logs should also be determined at the same time. Where trees are present and their buried remains are abundant the cost of getting the ground ready for digging the peat will be very materially greater than in a grass-covered bog. On the other hand, the wood may be sold or used for fuel at the plant, and the work of clearing may be done at times when weather or other conditions are unfavorable for production, thus keeping the force of laborers at work. It is also apparent that only a small area will be used at a time, and that the preliminary work will, therefore, be distributed over a long period, so that its cost per ton of peat produced will usually be so small as to be insignificant.

When all things are taken into account, however, and a choice of bogs can be made, that which has many buried logs and stumps should be avoided. If the woody material is confined closely to the surface layers, little account should be taken of it, because it is easily removed. The deposit below such layers is often more decomposed and compact than where trees have not yet become established.

DRAINAGE OF BOG.

In European countries, where peat is dug extensively by hand, the general practice is to plan and carry out an elaborate system of drainage, so that the water content of the peat is perceptibly lowered before digging is begun. Aside from the greater convenience in digging insured by drainage, the water content is lowered to a considerable extent, although not so much nor so rapidly as would be expected, because of the water-holding powers of the peat.

Drainage becomes of importance, however, whenever the greatest economy of handling the wet peat is sought, as it should always be if dug .by hand. Reference to the table giving the relation of the percentage of water in peat to its weight (p. 110) will show that, if the water content of a given weight of peat is reduced from 90 per cent to 80 per cent, its weight will be decreased 50 per cent, or one-half. Hence by lowering the water 10 per cent only one-half the weight of wet peat that would have to be dug before the reduction has to be dug out and handled for a given weight of finished product.

Drainage may be unnecessary, or even undesirable, where the peat is to be dug and transported from the bog to the factory by machinery, especially if it is to be dug by dredges, loaded on scows, and towed in them across the water-filled openings already made to the factory. It would be still less desirable to drain where the peat is to be dug and moved from the bog to the factory by powerful rotary pumps, such as are employed on the "sand-sucker" dredges so often used to improve waterways and harbors in the United States.

Before draining is decided upon as a policy in any given instance the possibility of draining the deposit must be determined. Although this could seemingly best be determined by taking levels, there is an important relation between the structure of the deposit and drainage possibilities which, if observed, will be of much assistance and may render surveying unnecessary. Bogs of the built-up type—that is, those which show a uniformity of structure or the presence from bottom to top of the remains of such plants as always grow near or slightly above the ground-water level—can be drained to the bottom or as deep as such structure is found.

On the other hand, peat that fills basins formerly occupied by ponds and lakes can be drained only for a short distance below the surface, or not at all, except at great expense, as the outlet must sometimes be lowered for a long distance. An attempt to drain peat beds of this type more than a few feet by surface ditching will, therefore, be unsuccessful, and peat will generally be most easily and most cheaply worked without any attempt at draining unless diking and pumping are adopted. Deposits of this class, as they lie chiefly below the water level and can not be drained, must manifestly be worked almost entirely by machinery, unless the water is kept down by

pumping or by sinking tubular drainage wells to porous beds in the ground below the basin, as may sometimes be done.

In bogs filling basins ditches should not be cut from the shoreward margin to open water in the interior of the marsh without very careful leveling across the surface, because not uncommonly the surface of the water in the pond is higher than that in the marginal area and water will flow from the pond and not into it.

That utilization of peat bogs in the United States under existing economic conditions necessitates drainage remains to be proved. Where digging by hand has been tried it has been very slow and expensive and has been an important contributory cause in the final failure of the plants adopting the system. If draining is decided upon, levels must be taken carefully to determine the direction and fall of the surface, and surveys must be made of the distance to the nearest main established stream. After these data have been collected draining will proceed much more cheaply and more satisfactorily if excavation is begun at the outlet end of the bog and continued as development progresses toward the higher parts. Such a course will make the system of drains as simple and short as possible and will reduce thereby the cost of the work, and by keeping them wet will also protect the undeveloped parts of the bog from loss by fire and injury from freezing. Where machine peat is to be made from a drained bog the ditches must be provided with dams to hold the water in them during the winter, as freezing injures the cohesiveness of the drier parts of peat beds more than it does those that are kept very wet.

CHOICE OF SITE FOR THE PLANT.

The choice of a site for the plant would seem to be a simple matter and not of sufficient importance to merit much discussion, but when it is remembered that from 80 to 90 per cent of the material brought to the plant is water (and therefore waste) it becomes evident that by reducing the distance of the average haul of the wet peat a material saving in the cost of this transportation and production will be made. The permanent buildings of the plant, therefore, should be so placed in relation to the bog to be worked that the raw wet peat will reach the grinding machinery by the shortest and most direct route; from the grinding machinery it should be taken as directly to the drying grounds or sheds.

An ideal arrangement, especially in the manufacture of machine peat, is to have no fixed buildings, but to have the movable machinery always at the side of the openings from which the peat is taken, and to pass the peat directly from the mechanical excavator to the pulping machinery and thence to a part of the bog near by that is laid out as drying ground. To insure such mobility of plant, the machinery

may be mounted on a strong car and moved on iron rails or upon rollers or broad-wheeled trucks; the engine is used to run the plant and as a locomotive. This is the common practice in many parts of Europe. The plant is much the same temporary sort of an arrangement as a portable sawmill or thrashing outfit. The most recent practice in Germany, Canada, and the United States is to combine digging, macerating, and spreading machinery into a single self-propelling plant which is supported on a single platform with or without rails.

However, in some cases it will be desirable to place the machinery on solid ground, because there are difficulties in moving peat machinery of large capacity from place to place on the soft and unstable surface of the wet peat. If the moving of the wet peat is the ruling consideration, the plant ought to be placed as near as possible to the bog, the necessity of a firm foundation and convenient approaches and drying ground being also observed; the hauls necessary to get the freshly dug peat to the buildings should average as short as possible during the life of the plant. The best location would ordinarily be about midway of one of the long sides of the deposit.

If, however, more satisfactory transportation arrangements can be made, a more stable supply of labor assured, or better drying ground obtained at some point other than the one indicated, these practical matters should determine the selection of the site.

LAYING OUT THE PLANT.

Several factories in the United States have been built for making peat fuel in which, seemingly, no thought or care has been given to laying out the plant so as to secure the greatest efficiency from the machinery and economy in the details of production. This is evidently a radical defect in such plants, if the highest financial returns are sought, as these are dependent upon successfully solving the following problem, stated in terms of the unit of production. The problem in peat-fuel manufacture is so to handle a ton of wet peat (containing 90 per cent of water, nearly all of which is useless) as it is dug from the undrained bog that the approximately 225 to 250 pounds of salable materials (containing 12 to 20 per cent of water) which will be obtained from it can be sold in the open market at a price that will pay for the digging, preparation for sale, and cost of selling, and, in addition, maintain the plant and equipment and return a profit on the investment. The handling of many tons of this wet raw material and the production of a large amount of marketable fuel only complicates matters if the unit of quantity is made at a loss, and manifestly any saving in the course of proper preparation will help to give a favorable solution of the problem.

The machinery should be so arranged in the building that its best operation requires the least possible labor and supervision and that the various processes through which the peat must be put will become automatic or go on with the minimum amount of human labor and attention. Careful study should be given to the entire course of production and whenever simple and efficient machinery can be substituted for manual labor, it should be introduced, if possible.

The fact must not be lost sight of, however, that a product of such low selling price as peat is much more likely to be manufactured profitably if the machinery used is simple and the processes through which it is made ready for sale are few and direct than if complicated and high-priced machines and numerous operations are required.

SELECTION OF PROCESSES AND MACHINERY.

The process by which a given peat bed can be utilized to the best advantage and with the greatest profit depends, among other factors, upon the quality of peat, the kind of market which can be reached, and the amount of capital which is available for the purpose. Not all kinds of peat will make good briquets, even with the best machinery, and it would be a needless expense to erect a large and expensive plant in a region of limited population, or where coal or other fuels are very cheap. It would obviously also be a poor policy to choose a process which would need a large investment of capital when an equally salable type of fuel, whether actually as good or not, could be made with a much smaller investment. It should be remembered that there is no such thing as a really secret process for making peat fuel, that when the time comes for selection the number of available processes is not large, and that all such processes have often been described by European authors or by others discussing the use of peat in Europe.

It should be the chief concern of the purchasing agent before any decision is reached to learn everything possible about the progress of peat-fuel production in Europe, and especially in Germany and Sweden, where, for more than a century, experienced men with keen, well-trained minds and ample facilities have been studying the possibilities of the substance and have been testing ways in which they have thought it could be most cheaply and readily made into an efficient and salable product.

After obtaining this information a careful examination should be made of the kinds of machinery now on the market as the practical result of the world's experience. That type should be chosen which has proven most efficient and successful in actual operation under con-

ditions similar to those under which the proposed plant is to operate. With so many available types that have been thoroughly tested by commercial use it is not advisable to adopt new and untried processes and machinery for a plant that must be made financially successful from the start.

However, after machinery embodying the latest European knowledge has been tried, modification and adaptation to the conditions of production which experience has brought to light may seem advisable. Such work can be done much more satisfactorily after a preliminary test than at an earlier time before any practical knowledge had been gained. Indeed, it seems that much more real progress would be made by American inventors in developing machinery for manufacturing peat fuel if they started with the best European types as the basis of their plans rather than with an attempt to start from the beginning.

CHARACTER OF THE PLANT.

The size of the prospective operations, the process of manufacture chosen, and the amount of capital to be spent will govern to some extent the necessary expenditures for buildings and machinery. Aside from these factors, however, expediency and the actual needs of the business should govern the character of the buildings.

The permanent buildings needed for a factory making machine peat are few and can be of the simplest and cheapest construction consistent with durability for the expected life of the plant. All that is actually required is sheds for the protection of the boiler, engine, and grinding machinery and for drying and storing the peat. As production is limited to the warm months, heating and lighting in the winter do not have to be considered. This fact may also be taken into account in the construction.

In Europe many establishments making peat fuel have no permanent buildings, except for storage, as the machinery is all movable and is given temporary housing at the places on the bog where it is in use. Each peat machine makes a certain number of tons per day and the plant is added to by the purchase of new units as the need for increased output arises. The same would be true if self-propelling automatic machines were used instead of the standard older types.

If peat briquets are to be made, somewhat larger and more substantial buildings must be erected, because more machinery of heavier construction must be housed; yet even for the briquet plant the buildings may be built as cheaply and roughly as sawmills. The chief requirements are that the roofs keep out the rain and that the foundations for the presses, boilers, drivers, and engines be of sufficient strength. A simple, inexpensive, compact, and well-arranged

plant of moderate capacity, increased unit by unit, is much more advisable than large and costly buildings containing small equipment.

Peat-coke, or charcoal manufacture combined with the recovery of by-products, requires a heavier investment for buildings to house the much greater quantity of apparatus necessary, and these must be of good construction, because the plant will be operated the entire year. Practically the same statement applies to the buildings that would be needed for utilizing peat for gas production. Even for for such uses, however, care may be exercised to keep down the outlay of construction by making the necessary buildings simple and inexpensive. Some of the buildings which have been erected for peat-fuel factories are monuments to the dreams of their builders.

WORKING CAPITAL.

The preceding sections show that a considerable number of factors must be taken into account preliminary to operating a peat-fuel manufactory. One of the most important is a definite and full provision for working capital for the maintenance and running expenses of the plant for the time that will surely be needed to develop it to a state of efficient production and to build up and establish a market for its output.

An examination of the history of the attempts to start peat-fuel operations in this country seems plainly to show that many of them have failed because of insufficient working capital. Money enough generally has been provided for actual building and partial or complete equipment of factories, but the projectors apparently have been so certain of success that they have deemed it sufficient to plan to produce peat fuel, and to build and more or less fully equip their plant therefor. Beyond this, they have often seemed to expect that the anticipated product would make and market itself with so much profit that necessary additional equipment could be had, dividends on the original investment paid, and the production continued indefinitely with increasing impetus.

This is not the usual result of an attempt to introduce a new and practically untried and unknown article that competes with one that has been long in use and that is acknowledged to be superior in some respects. In the cases under consideration, when the investors did not immediately realize their anticipated profits, they lost faith and refused to furnish additional money, often before their plants had advanced to a stage where commercial manufacture was possible. Such a result might have been foreseen in some cases and should have been provided for in all, as frequently is done in other kinds of business, by reserving a certain part of the funds at hand for carrying on the business through its period of experimental production. If

such action had been taken, and later the necessity had arisen for increased facilities for production, the money for them would have been available.

To make no provision for working capital must be looked upon as a most serious error in business policy, and the conclusion seems warranted that those who start and promote enterprises for peat utilization in the United States at present without such provision are inviting the same troubles that have beset their predecessors, and can expect no greater success.

CAPITALIZATION.

The capitalization of peat enterprises, as stated in the preliminary literature issued by their promoters, has varied greatly. At least one reported an authorized capital of $20,000,000. Obviously, however, certain definite matters control the sums of money which must be provided to establish a plant for using peat and to bring it to a successful stage of production, and these are here considered. In general, it may be said that large capitalization is neither needed nor desirable for most forms of peat utilization, but it is important, as has been noted above, to have reserve capital for use during the critical periods of the proposed factory. The amount of capital actually needed will differ for different products and for different ways of making the same products; it will be governed also by the proposed quantity of output, the size and kind of buildings to be erected, and other factors which do not need to be taken up here. The simpler processes of peat-fuel making on a moderate scale can be undertaken and carried on with success on a small capital. Some of the more complicated operations, such as making peat coke and by-products, or those peat products requiring heavier machines, more manipulation and labor, and stronger and more expensive buildings, must be liberally supported with money or credit if any returns are to be derived from them.

A much greater amount of capital must be assured and actually paid in, as required, to bring to a commercially productive and independent stage a plant that is equipped with machinery invented to exploit some new way of treating peat than would be needed to do an equivalent amount of development with machinery that is already on the market and has proved satisfactory in actual manufacture of the product which it was designed to make. This statement is warranted by the experience of many of the more aggressively advertised experiments in peat development which have been made in America and Europe. These experiments have invariably taken much more money and time to bring to a state of completion than their inventors anticipated; and some, after all, have failed.

EXPERIMENTAL WORK IN NEW PLANTS.

The past uncounted waste of time and money in this country in what is called experimentation demands a brief notice. Experimentation has generally signified the random use of the whole or a part of a plant and its force of laborers for the purpose of testing some of the ideas of the man in charge or of some of his associates, in the hope that the process or machinery in use may be advantageously supplanted. The futility and waste lie more in the way in which the work is generally carried out than in the ideas themselves. Usually experimentation of this sort is attempted without the appliances for exact methods and without the originator having any clearly developed plans as to what is needed or how the work is to be conducted; yet it calls for much energy and money, and in the end counts for nothing. If the same amount of work and funds were used to raise the efficiency of the working force and of the machinery already in use, much of the experimenting would be entirely unnecessary. Sometimes the men who propose the changes are entirely without experience and training, or have only elementary knowledge, and the work which they do is nearly all lost. It appears certain that the men who have come nearest to success or have had the greatest success in making peat fuel have done so by avoiding as much as possible the expense of the sort of experiments described. They have developed their plants to profitable production by learning in practice from day to day the peculiarities of the substance with which they worked and the conditions required for making the best product possible with the machinery and process which they had chosen.

It must not be understood that properly controlled and carefully planned experiments may not lead to valuable results in the making of products from peat, but in so far as this work is done by inexperienced and untrained men, and diverts time, money, energy, and work needed to improve the commercial operation of the plant, it is a source of injury and positive loss, and may destroy what would otherwise be a profitable business.

It may be said in closing this discussion that in the writer's judgment the adoption of untried machinery for peat manufacture should always be considered as a purely experimental or speculative investment, especially if only working plans and calculations are submitted as the basis of the proposed plant. Only that machinery which has been actually used and has shown what it will do under approximately commercial conditions should be the basis of a factory from which it is necessary to get quick financial returns.

It has been the history of the development of all mechanical and chemical processes that they have developed slowly and by repeated and often costly failures. The more thoroughly and completely

the processes are dependent for success upon the proper operation of a number of machines working in harmony for long periods of time the longer the period of development must be. In the history of peat-fuel enterprises in Europe this fact is emphasized again and again. At the present writing announcements are made of the reduction to a commercially possible stage of two important nearly continuous processes for utilizing peat. These processes have been before the public for a number of years as theoretically valuable, as demonstrated by laboratory experiments, but only now have they been sufficiently worked out in the details of the machinery needed for turning out the finished product on a scale and at a price that warrants the erection of the large plants required; the latest authentic information indicates that these have yet to be built.

CUT PEAT.

In Ireland, England, Denmark, Germany, and the other countries of Europe where peat is a common domestic fuel the simplest and most ancient method of preparation is still most commonly used. In Ireland, where nearly all of the fuel consumed by the country people is peat, no other process of preparing it has ever been used to any appreciable extent. Within a few years, however, the Department of Agriculture and Technical Education has established several temporary experiment stations for the purpose of introducing to the people the treatment of peat and its manufacture into fuel by simple machinery, most of which is of German origin.

The preparation of cut peat and the equipment for making it are so simple that the owners of small peat deposits can easily make fuel for home consumption. On this account a somewhat detailed description of the methods of procedure is given here, although the product is such that probably it can have only a very limited use in the United States.

After the surface of the part of the bog that is to be used is cleared, it is drained to the nearest watercourse by a ditch of good size. Into this main ditch are led a number of smaller ditches of sufficient capacity to lower the general water level in the peat at least 2 or 3 feet.

The part of the field to be worked is then chosen and more carefully cleared and leveled, so that its surface may be used as a drying ground. If this area is selected near the margin of the main ditch, it will be more easily and cheaply drained than if it is at a greater distance, because the water will already be lowered there, and the transverse ditches when dug will be as short as possible. Such small transverse ditches on the drying ground are made about a foot wide and with enough slope to the bottom to carry off the water that collects in them; they are generally placed from 30 to 60 feet apart.

If the bog can not be drained cheaply by ditching, an opening may be made near the place selected for beginning work. The water can be pumped from this opening from time to time as it accumulates and can be conducted away from the immediate vicinity of the hole and the drying grounds. Care should be taken not to let water into such a hole by digging into the sands below the peat.

The tools used for making cut peat in different European countries are somewhat different in size and shape, but they are always of the simplest form and construction and differ only slightly from those used in ordinary ditching and digging. In Ireland, the most important special tool is the slane, a stout narrow spade having the length and width of the bricks to be cut. It has a narrow sharp steel lug welded on one side of the point of the blade and at right angles thereto. Some types of spades used for peat cutting in Germany have two of these lugs, one in the middle of the blade and the other at one side, so that two bricks can be cut at once. The size of the bricks varies in different countries according to the purposes for which they are to be used, the moisture conditions under which they must be dried, and the density and structure of the peat. The usual range is from 8 or 10 to 18 inches in length, and from 4 to 7 inches in width by 3 to 6 inches in thickness, when the bricks are freshly cut and wet.

The men generally work in pairs, a digger and a tender. The turf is first removed from a strip at the end of the ground prepared for digging and the peat below dug out in the form of bricks of as nearly uniform size as possible, and placed to one side. The tender picks them up, loads them on a car or wheelbarrow, wheels them to the drying ground, and lays them out for drying. As soon as the peat has been removed from a depth twice the length of the spade, or, more often, to the depth of the ditch bottoms, a new cut is started, the digger working in the trench to make the horizontal cuts, which are the last ones to be made. The vertical cuts are made with a straight spade or spadelike knife, the operator first making the wall cut at the length of the block from the last cut. The cuts forming the sides of the blocks are then made the width of the block apart; the horizontal cuts are made from the trench, and determine the thickness of the block.

If the peat is very thoroughly decomposed and structureless, the blocks may possibly be cut with the long axes vertical, using the slane, but where stratification is well marked or the peat fibrous this way of cutting causes the blocks to be easily broken along the lines of bedding; hence in most cases the length of the block is cut parallel to the planes of bedding. The slane may be used to cut the bricks out after the first vertical cut is made along the wall, especially where the peat is dense enough to be cut easily.

After the blocks are taken to the drying ground they are stood on edge, with narrow spaces between them, and allowed to dry and drain for some days; in some countries they are turned during this time. In Ireland, as soon as they are firm enough to be handled they are "footed," or stood on end, generally seven in a small circle and two others crossed on top of the group. After a week or two, in good drying weather (or longer in bad weather), the blocks are "refooted" by turning them and combining two piles into one. In about four weeks they are ready to be removed and stacked. The bricks are piled in an open manner so that the air can circulate freely through the piles, and the peat is often left in these stacks until needed for use, the top being protected by a thatch or by a shed roof. If dried too rapidly, the product cracks and is brittle, and in this country stacking to check the drying may have to be resorted to in less than four weeks. In different countries the methods of piling the still moist peat blocks vary somewhat, but any open form that gives free access of the air to as much of the block as possible will serve. Where lumber is cheap, racks similar to those used in brickyards may be used to advantage for the preliminary drying and will hasten it by some weeks.

Peat blocks of the sizes given weigh from about half a pound to a pound and a half when they are air dry or contain from 15 to 30 per cent of moisture.

The cost of producing peat in this form varies with the cost of labor and the skill of the laborers who do the work. In Continental Europe, where this sort of work is usually paid for by the piece, the men getting a fixed price per thousand bricks in each of the processes of digging, spreading, etc., the fuel is made at from 50 cents to about $1.75 per ton of air-dry peat bricks. The efficiency and price of labor and the different ways of handling the product are the only apparent reasons why the price should greatly vary. Cutting and drying peat for fuel should be done as early in the season as possible, because the product dries much more quickly in spring and early summer than later, and when the gathering is put off till August the peat may not get thoroughly dry before winter.

Cut peat is the poorest form of peat fuel, as it is bulky, friable, and burns up rapidly with considerable waste when thoroughly dry. In general, this kind of fuel may be considered as unfitted for American fuel markets; its chief use, if any, will be in the homes of its producers. The dark-colored, thoroughly disintegrated peats make the best cut bricks, and the light-brown, fibrous kinds the poorest, except for kindling.

In some parts of Europe, however, cut peat is still used to a considerable extent, even in the towns. Where it is made on a large scale machines are used to dig the peat, as these give the advantage

of producing large blocks quickly, even from undrained and undrainable bogs which could hardly be worked by hand.

The essential part of such machines, which differ mainly in the details of construction and not in principle, is a series of three vertical iron or steel plates edged with steel knives. These plates are arranged in the form of a bottomless box from which one side has been removed and are supported and moved by simple machinery. The knives are forced into the peat to the desired depth by a strong rack and pinion operated by a crank turned by hand. The column of peat thus formed is cut off and supported at the bottom by a horizontal knife that is forced across the bottom of the box formed by the three vertical knife-edged plates. The horizontal knife is operated by a powerful lever worked from the surface. The column of peat, held up by the horizontal knife, is then raised by reversing the motion of the crank, and as it is brought above the surface it is cut into bricks with a spade, just as when cut by hand.

Some machines of this type will cut peat to a depth of more than 20 feet. They usually can be operated by two men; one raises and lowers the cutting apparatus and the other cuts up and loads the peat on barrows or cars, in which it is wheeled to the drying grounds. Where the peat is cut from considerable depths by large and heavy machines, three or four men may be needed to each machine. Peat-cutting machines of this sort are strongly built, but may be moved from point to point on the surface of the bog as digging progresses. The guide for the knife can be moved so that a trench several feet wide can be cut without changing the position of the whole machine.

MACHINE PEAT.

GENERAL STATEMENT.

The term "machine peat" following German practice, has so generally come into use to designate peat that after being dug has been treated to a process of grinding or macerating and pressing before forming it into bricks that it is used here. Terms which are nearly or quite equivalent are press peat, pressed peat, condensed peat, machine-formed peat, and wet-process peat, so called in the United States to distinguish it from briquetted peat, which is thoroughly dried before being formed into blocks by great pressure in a briquetting press.

Cut peat as a fuel that is to be used, or even produced, on any considerable scale has well-marked defects, such as lack of uniformity, firmness, and density, small fuel value per unit of volume, and a high percentage of water frequently found in it even after prolonged drying. These defects led to early efforts to work the raw material into a more compact and durable form which would dry more thor-

oughly and quickly and would be more dense and therefore easier to to transport. In general the earliest experiments in this direction were made to improve the quality of the very fibrous kinds of peat. So much was gained by even the crudest treatment that gradually in the more progressive peat regions all types of peat were treated in this way, and cut peat was only sparingly made by the larger enterprises. By the effects of the mechanical treatment mentioned above, the plant remains in the peat are reduced to a fine pulp, and their water-retaining capacity is lowered considerably; hence peat that has been thoroughly ground and mixed dries more quickly and forms denser fuel than that untreated. Within limits the more thorough the grinding and pulping and the more quickly the drying takes place, the more compact is the resulting fuel and the better its quality.

In theory, at least, when peat has been thoroughly macerated, a block of it is soon covered by a thin coating of a colloidal or glue-like material, which becomes nearly waterproof on drying, but which is sufficiently porous to allow moisture to pass through it from the inside of the brick. Possibly also this coating, when wet by rain, absorbs enough water to close up the minute openings which exist in the surface when it is dry, and thus prevent further absorption. Hence after a heavy rain properly ground machine peat is nearly as dry as it was before, whereas cut peat takes in a large amount of water and if the rain is prolonged may be much disintegrated. At the same time the contraction of the outer layers of the brick as they dry out exerts a certain pressure on the water contained in the interior, and thus probably forces it out toward the moister side, which in this case is always the one lying on the ground or on which the brick is supported.

METHODS IN USE FOR MACERATING PEAT WITHOUT SPECIAL MACHINERY.

There are two quite distinct processes used for macerating peat without special machinery: First, that in which enough water is added to the peat before it is macerated to make it into a soft paste, which, after treatment, is often decidedly liquid. This pulp is usually formed into bricks after it is spread on the drying ground. The forming is done either by hand, whence the name hand turf sometimes given the product, or by turning the pulp into molds. Less often the macerated peat is spread in a layer on the drying ground and cut into the required shape with special tools, the bricks thus formed separating through contraction as they dry.

By the second method the peat is ground with practically the same amount of water that it contained when dug and is forced from the orifice of the grinding machine in one or more continuous prismatic or cylindrical strands, which are cut into bricks as they emerge from the machine; some types of machines form the peat pulp into balls;

others perforate the bricks to facilitate drying. The product is machine peat in the usually accepted sense of the term, and the principal variations in its manufacture are all found in the details of construction of macerating machines and in drying the peat.

The simplest and most primitive modification of the first process, as used in Ireland and in other parts of Europe where no capital is available, is the following: The coarse, fibrous top layers of the peat are thrown into the hole made by the previous season's work. If sufficient water is already in the hole, the coarse peat is thoroughly mixed by trampling with that of finer texture in the hole, until the mass is of uniformly fine grained and pasty consistency. After this mixing is completed the ground peat is taken to the drying ground and spread in a layer from 8 to 12 inches thick, and the bricks are marked off by hand as the spreading proceeds. Only slightly more complicated than this simple process, is the use of wooden troughs for holding the peat and water while the maceration is going on, or the substitution of the feet of horses for those of men for mixing the peat and water.

In larger enterprises with some capital the peat is ground and mixed with water by machinery, a simple form of which is made by placing in the trough a rotating axis, to which are attached spirally-arranged knives and which is turned by horse or steam power. The peat and water are thrown into the upper end of the trough and mixed and reduced to a slurry while being moved forward by the revolution of the knives. At the outlet end the slurry is removed in cars or barrows to the drying field and is sometimes turned into sets of wooden or metal molds, in which the sections have the dimensions of the bricks to be made.

The mass of peat is tamped into the molds and smoothed off, and after a short time, the surplus water having drained away, the bricks are easily removed and are then laid out on the drying ground to drain and dry, after which the procedure is the same as in drying cut peat.

In Denmark and Sweden, where women and children are hired to do the work of turning and piling on the bricks on the drying ground, the cost of producing this type of peat on a large scale varies from $1.25 to more than $1.50 per ton.

The manufacture of peat fuel by any of the various modifications of the above-mentioned processes does not seem feasible in the United States except on a small scale, since the hand labor required is considerable, and the product is no better and quite as expensive to make as the better-known machine-formed peat, which is taking its place abroad.

Machine peat, as the name is commonly understood, is made by grinding the peat with about the same amount of moisture that it contains in the bog and cutting it into bricks as it issues from the

outlet of the grinding machine in a thoroughly macerated condition, but sufficiently stiff to retain its form.

REASONS FOR EXTENDED DISCUSSION OF METHOD OF MANUFACTURE.

This method of manufacturing peat into fuel by machinery is somewhat thoroughly discussed here because it is so widely applicable to all kinds of peat, whether well or poorly decomposed, fibrous or compact, light-colored or dark. The equipment needed for successfully carrying on the process is modest, and the investment of capital small compared with that required for the more elaborate coking and briquetting processes. The experience needed for using the method is also much less than with either of the others. The discussion seems to be warranted also by the fact that many trustworthy observers report that it is the only way yet found in Europe for making peat fuel for general purposes and in quantities at a profit, except at a few plants referred to under briquetting and coking (pp. 120–139).

The opponents of this method of making peat into salable fuel say that it leaves much to be desired, not only mechanically but in the quality of the product, which for some purposes is not an ideal fuel. The product is, however, solid, tough, and of rather high specific weight. Where it has failed to give satisfaction under boilers in the United States the cause has been faulty construction of the fire boxes. In Amsterdam, Holland, machine peat sells at a retail price equivalent to $5.80 for the lighter grades and $6.30 for heavier grades, when coal may be bought at about $4 per ton. Evidently, when people are accustomed to it and know how to get the best results from its use, machine peat has decided advantages for domestic use.

EARLY PEAT PRESSES.

The manufacture of machine peat began in Europe at least as early as 1820, when crude wooden machines were in use in Saxony. The use of similar machines was reported shortly afterwards in England and Ireland.

These early machines really attempted to form the peat into blocks and to squeeze the water from it at the same time by powerful screw presses. These failed to give very satisfactory results, however, and hydraulic presses were afterwards tested, both alone and in combination with macerating apparatus. The machinery was slow in action, expensive to run and maintain, and the results, after repeated trials with many types of presses, so uniformly unsuccessful financially that the idea of pressing the water from the peat was reluctantly abandoned. The reports on these machines show that the best and most powerful presses rarely reduced the moisture content below 65 to 75 per cent and gave a very small daily output. Besides these difficulties, the drying of peat by pressure resulted in forcing the finer

and more completely disintegrated parts of the peat with the water into and through the cloth used to retain the peat in the press. The pores of the cloth were thus stopped so completely after a short time that water could be forced through it with difficulty or not at all; sometimes, also, the peat would expand again after the pressure was taken off.

At the present time there is a revival of interest in this country in the possibilities of using great pressure, vacuum pumps, sieves, and similar devices for drying wet peat. Those inventors who are attempting to develop processes depending on these and like principles will learn what to avoid by a careful study of the types of peat presses developed by German experimenters and abandoned in the middle of the last century, as described in the older standard European peat manuals.

ESSENTIAL PROCESSES.

In considering the development and construction of a factory for making machine peat, the following processes must be provided for: Digging the peat, transportation to the machine, grinding, removal to the drying grounds or sheds, care during drying, and, usually, subsequent stacking and storage. If, as is often the case in Europe, the peat machine is placed on the bog at or near the opening from which the peat is dug, the second process is eliminated, as the material may be dug and placed in the machine by one operation, either by hand, by a dredge bucket, or by a mechanical digger and elevator. Digging, macerating, and spreading form a continuous, automatic operation in the latest types of self-propelling, portable plants now being tested in America and Europe.

DESCRIPTION OF PEAT MACHINE.

The peat machine, or mill, is the important part of the plant, and should be the focus of all the other parts. Especial attention should be given to the importance of having each stage of the manufacture as nearly continuous with the one before it as possible.

The peat machine has been developed rather slowly and the best models are of strong and simple construction. In principle and form the latest types are much like the pug mill or grinding machine for plastic clay. Some of the experimental plants in the United States have used ordinary brick or tile makers' pug mills, with very slight changes, to grind peat, especially that with little fibrous matter, and have found them well suited for the purpose.

The earliest German peat machines of this type of construction appeared about 1860 and were vertical iron cylinders, in the upper part of which knives, fastened to a slowly revolving axis, cut and ground the peat. It was then subjected to pressure by a revolving

screw at the lower part of the cylinder and forced through a rectangular tube, opening at the side of the machine. This shaped the mass, which as it issued from the opening was received on movable boards and cut into bricks by hand. This type of machine worked well with structureless peat, but its operation was slow and the knives soon became clogged when fibrous peat was introduced into the cylinder. The type has gradually given place to one having a horizontal iron cylinder and a swiftly rotating axis armed with spirally arranged knives and flanges. These act as screws to press the peat forward to the constricted outlet end of the cylinder, while they are mixing and macerating it, and in passing through them the peat is reduced to a fine-grained or structureless, homogeneous pulp.

TYPES OF MACHINES.

The most recently devised and efficient form of this class of machines has a hopper for receiving the peat at the inlet end, doors in the outer casing, by which all working parts can be easily reached, and a device for cutting the strand of peat pulp into bricks of uniform length as it issues from the orifice. In some models the vertical body is still retained, in others there is a combination of vertical and horizontal cylinders. In some machines the knives are separate from the screw flanges, but mounted on the same shaft with them; in others the flanges of the screw are sharpened and work against stationary knives set fast in the cast-iron walls of the cylinder; still others have both fixed and movable knives, the cutting edges of which work together like the blades of a scissors; a few models have been built and placed on the market, with two knife-armed shafts revolving in opposite directions. Many types of peat machines have been patented in the United States, but few of them have ever been really used, and most of them follow European models.

European manufacturers make peat machines in all sizes. The smallest are run by the power furnished by a single horse, and with the help of a few men turn out 3 or more tons (air-dry weight) of peat bricks per day. The largest must be equipped with powerful engines and accessories and require the services of from 15 to 25 men and boys to dig the peat and handle the 60,000 to 80,000 peat bricks, amounting when dry to 50 or more tons of fuel, made in a successful day's run.

DESIRABLE QUALITIES OF MACHINES.

In all of these variations in the form of peat machines, the purpose is to reduce quickly and effectively to a fine pulp all of the coarse matter found in the peat. This also must be done with the fewest possible delays from breakage of parts of the machine or from clogging caused by the fibers of the peat winding around the shaft or the

knives, or from pieces of wood or even of stone becoming fast in their passage through the machine.

The possibilities of such obstructions require strong and heavy construction and easy accessibility of all working parts so that they can be quickly cleaned when clogged, and replaced when broken. The best peat machine to purchase is the one which will most rapidly and completely grind the greatest quantity of peat in a given time with the least power and attention and will produce a uniformly well-macerated pulp from all types of peat that are suitable for fuel. Such a machine should be strong and simple, and its parts should be capable of being quickly and easily reached and adjusted when necessary. In most of the peat machines now in use the grinding parts are made so that their angle of setting can be changed according to the kind of peat that is to be manufactured—a most necessary improvement where peat is as variable in structure as it is in the United States.

Many models of peat machines of the type just described are manufactured in various European countries, and a few excellent ones are advertised as manufactured in the United States; from among them all a form to meet almost every need can be found.

The principal types of European peat machines of modern construction are fully described and illustrated in a recent publication of the Canada Department of Mines[a] to which the reader is referred for further details. Reference to the catalogues of the manufacturers in this country and Europe is also suggested.

The most efficient of the machines now in use, under favorable conditions of operation, reduce by about one-third the bulk of a mass of wet peat as it passes through them. This is done partly by squeezing out a portion of the water, but more of the condensation is caused by crushing the fibrous and woody structures, and by releasing included gases during the maceration and kneading that the peat receives while in the machines. There is little true compression, as the pressure exerted on the peat is not sufficient to remove much of the water from it, and because the peat is not confined, such pressure as is brought to bear upon it only causes it to move forward in the cylinder and flow freely from the outlet.

METHODS OF MOUNTING MACHINES.

Peat machines are mounted in several different ways. Some designed to be used on the bog are placed on timber platforms, either on rollers or trucks; others are mounted on cars, together with the boilers and engines used for running them, and the whole plant takes up little space and is very portable, so that it can be moved

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[a] Nystrom, E., Peat and lignite; their manufacture and uses in Europe; Canada Department of Mines, Mines Branch, 1908.

about wherever rails can be laid. This kind of mounting has been extended by the use of broad-tired iron or wooden wheels, or movable roller platforms such as are common on agricultural machinery in the United States; thus the entire plant becomes as mobile as a thrashing machine, the main factor being the weight of the larger sizes of peat machines. This weight, if properly distributed, is no insuperable matter, and in Canada in 1911 the largest size of peat machine is reported as successfully tried on a trackless self-moving portable plant. The practice of using movable rails, however, is satisfactory in most places, and as rails are used constantly for transporting the macerated peat or the finished peat bricks from machine to drying grounds and thence to storage or shipping point, they are always available.

DIGGING MACHINERY.

Until recently but little machinery has been used for digging the peat, which is the initial task of actual peat fuel production. By far the larger percentage of peat made into fuel in European countries is still dug by hand labor. Within the past few years, however, as larger machines and plants have been built, prominent makers of peat machinery have been constructing mechanical diggers operated by steam or electric power.

Power digging machines, so far as descriptions have been received, are either of the form of the hand-power machines already described (pp. 88–89) but of larger size, or of the chain-and-bucket type. The latter, although effective in peat of the more completely decomposed kinds, can not be satisfactorily used where stumps and other poorly decomposed tree remains are abundant, as they sometimes are, unless the machines are of very strong construction. The most recent models of this type of digging machinery developed in Europe are reported to be satisfactory. They have the advantage over other forms of diggers of mixing the peat from different beds, thus securing a homogeneous product.

DIPPER DREDGES.

In general, the dipper dredge, or its land equivalent, the steam shovel, would seemingly be more satisfactory and give better and more continuous service than the chain-and-bucket digger. Both have already been tried successfully in the United States in peat operations and are still in use at several plants where peat is produced.

The statement has been made that the dipper dredge can not be used because of the danger of including material from below the peat, but this, of course, is merely an operating detail, which can readily be provided for. This form of machinery will probably be much more freely used in this country as a peat industry develops than it has

been in Europe, as digging machines of some kind will be a practical necessity in the United States, whatever the type of material produced. It will always be necessary to dig a much larger weight of peat than will be sold. Thus a machine that can produce 50 tons of salable fuel in a day's run, if it is to be kept up to its capacity, must be provided with approximately 10 times as much raw material because the latter is about 90 per cent water and other waste. If the macerating machine is not kept busy, the productive part of the plant will be idle some of the time. To dig and move the required amount of wet peat by hand labor would mean a high labor cost, which could hardly be tolerated under existing economic conditions. Even in small plants where the excavating machinery would be idle part of the time its use will probably be found more economical and satisfactory than dependence on hand digging.

<center>AUGER DIGGING MACHINES.</center>

Many years ago in Canada a scow was equipped with very large augers, which, on being driven into the peat, dug it out of the bog and elevated it, making a canal as the digging progressed. Recently, in one of the experimental portable plants devised in the United States, augers of much smaller size and of different form have been used to excavate and macerate peat. Their use is reported to be satisfactory.

<center>MECHANICAL CONVEYERS AND ELEVATORS.</center>

All of the large peat machines manufactured in Europe are provided with mechanical conveyers and elevators, generally of the belt or chain-and-bucket type, and sufficiently long to reach from the bottom of the excavation to the hopper of the machine when the latter is placed near the opening in the bog. The peat as it is dug is thrown on the elevator, conveyed to the machine, and dropped into the hopper; thus time and labor are saved. The conveyers are usually operated and adjusted as a part of the peat machine, being placed either at one end or at one of the sides, and the same engine runs both.

If the peat machine is permanently placed in a building, the elevator may still be used, or it may be discarded, as the cars loaded with peat can be drawn up an inclined plane to a bin placed in a loft above the machine, and the wet peat can be fed from the bin by a gravity chute.

<center>TRANSPORTATION OF WET PEAT.</center>

<center>TRAMCARS.</center>

Machinery for transporting to the drying grounds the peat bricks, after the peat has been ground and formed in the mill, has been more thoroughly developed than that for digging, and several types have been more or less fully worked out by different makers.

These are, first, tramcars running on tracks temporarily laid on the surface of the bog, and pushed by men or drawn back and forth by horses or cables, or, in the United States, by electric or gasoline locomotives. Generally the cars used for this purpose have some form of open wooden or iron rack so that a number of tiers of wooden pallets full of the wet bricks can be loaded onto them, but where the peat is spread on the ground, wooden or iron dump cars are used. The tracks are usually laid out in such a way that the loaded cars go out to the drying grounds one way and return another, and that part of the grounds farthest from the machine is first covered. By systematic and careful planning, the tracks can be so laid that the number of men employed and the number of cars used for moving the wet peat bricks to the drying ground will be reduced to a minimum.

CABLE AND CARS.

In Sweden a system of cable transportation has been successfully developed by which the cars are drawn out and back by moving cables kept in motion by the engine running the peat machine. The track is movable and is laid out in the form of a rectangle with round corners. This arrangement reduces the number of men employed by as many as are elsewhere required to move the cars, one only being needed at the machine to fasten the clutch of the outgoing cars to the cable and to release those returning empty. The men who do the unloading attend to stopping and starting the cars at the drying ground. Obviously the cables in this system are adjustable and can be moved with the tracks as certain parts of the drying grounds are filled and others come into use. Provision has also been made for temporarily anchoring the pulleys through which the cables run. This system is in successful operation at the demonstration plant of the Canadian Government at Alfred, Ontario, and is reported to decrease materially the cost of handling the peat. In connection with this cable system, the peat is generally run directly from the peat machine into iron cars without bricking. Thence it is taken to the drying ground and there spread into a flat sheet and marked off into bricks by a device called a "field press." This is in effect a heavy sledlike platform with a number of thin knives extending out behind, which mark off the peat longitudinally as it is spread and compacted by the passage of the slanting platform; the cross-cutting is done by hand. The platform is slightly higher in front than behind and has an opening at the front end into which the peat is turned from the cars. The platform is moved in only one direction, away from the opening in the bog, and the motive power is a special cable operated from the engine; when it has been drawn the length of the drying ground in one direction it is placed on a specially built car and moved back the length of the drying ground

for a new start. By using this machine and the cables the number of men employed is reduced and the cost of handling the bricks materially lessened; the very considerable investment for pallets on which to handle the bricks may also be avoided entirely. This plan has been adopted at Alfred, Ontario, and is very effective and successful there. The peat bricks, after they have become dry and firm enough to handle, are turned and subsequently are stacked in small conical piles, and when sufficiently dry are removed from the drying grounds to the storage sheds or to cars on which they are shipped. The peat bricks are carried to the cars on barrows or light cars provided with racks, some of which are so built that their load can easily be dumped. Elsewhere the cars are simply platforms on which may be placed several handbarrows into which the peat bricks have been loaded as soon as dry.

CONVEYERS.

Another successful means of peat transportation is movable mechanical conveyers leading from the machine to the drying grounds and back. Such conveyers can be used in places where cars and tracks can not, but they are expensive to install and maintain—at least as made by the foreign manufacturers. The extensive use of various kinds of conveyers for many purposes about factories in the United States makes it seem probable that similar use of them could be made in transporting the loaded pallets of peat bricks to the drying grounds and in returning empty ones. It is also probable that some form of belt conveyer might be made to serve the same purpose.

CHAIN CONVEYERS.

An even simpler plan has been used in Florida. The peat is first ground and thoroughly reduced to a pulp; then, without being formed into bricks, it is conveyed by a common belt conveyer in a long movable trough to the drying ground and spread in a sheet about 8 inches thick by a specially devised spreader. This spreader is a wooden scraper mounted on wheels and drawn by a cable. The peat is not marked off into bricks, but as it dries and contracts it breaks into prismatic pieces, which are easily dried and handled. If, as was done at Orlando, Fla., the peat is piled in heaps after grinding, it dries slowly and must be cut into blocks before it can be used to advantage. This operation materially increases the cost of production.

AERIAL CABLES.

In a plant now being installed in Ireland for making ammonia from peat, cars or buckets moved by an elaborate system of overhead aerial cables are being used to carry the peat from the bog to the plant. This system is expensive but very satisfactory after it is once in operation.

CENTRIFUGAL AND VACUUM PUMPS.

When thoroughly macerated and sufficiently fluid peat is to be dried by spreading, it could probably be pumped from the machine to the drying grounds through iron pipes with flexible connections by centrifugal or vacuum pumps and spread by mechanical means.

DRYING ON RACKS.

A certain amount of time is gained in drying the peat on racks, as the bricks give up their water somewhat more rapidly when placed above the ground than when lying on it; they also need less attention and require much less space for drying ground; there is, moreover, less likelihood of considerable loss from rain. On the other hand, a larger number of pallets are required; these materially increase the first cost and add to the cost of maintaining the racks.

DRYING ON THE GROUND.

If the plan is chosen of drying the peat on the cleared surface of the bog, or of laying it out to dry on higher ground, a good sized area should be made ready by clearing off bushes and leveling, so that ample space will be provided; for if the output is 50,000 or more bricks of peat a day, a large area will be covered at the end of a short time. If too little space is allotted for this purpose, the entire plant may be kept idle just when all other conditions are most favorable for production. It may be said that in suitable weather the bricks are dry enough to remove from the pallets after a few days' exposure and may then be piled in small open piles or spread out on the ground and the pallets used again. If the peat is spread directly on the bog surface and formed into bricks by marking, it must be turned over at least once before piling. The best practice in air drying calls for storing the peat in covered piles when it still contains from 50 to 60 per cent of moisture. Peat so stored dries into tough hard fuel.

ADVANTAGES OF A COMPACT PLANT.

The advantages gained by confining all operations as closely as possible to the surface of the bog must not be overlooked. If grinding, handling, and drying operations are all kept as near as practicable to the place where excavating is going on and the finished product is all that is moved away, the waste, chiefly water, is left on the bog and the moving of the greater part thereof is avoided.

In making plans for equipment it is clearly better to install a small complete plant, with only necessary buildings of cheap construction, than to equip inadequately a large plant housed in expensive structures. It should be kept constantly in mind that the output of a

well-arranged small plant can be practically doubled by duplicating a part of the machinery, but that a small output from a large machine, with too little power and too few accessories, can be obtained only at a considerably greater cost per ton than from the more complete installation.

REQUIREMENTS FOR A COMMERCIAL PLANT.

In planning to make air-dried machine peat on a commercial scale the following factors must be regarded as essential to success:

(1) Railroad or other cheap transportation from the plant to the expected market.

(2) A good-sized area of peat of workable thickness.

(3) Machinery for excavating the peat.

(4) A peat machine of approved and thoroughly tried pattern.

(5) Cars and portable tracks or suitable mechanical conveyers for moving the wet peat from the openings in the bog to the machine, from the machine to the drying grounds or racks, and thence to the storage sheds, or to cars for final shipment. The self-propelling portable plants that combine digging, macerating, and spreading machinery simplify or eliminate (3), (4), and (5).

(6) Ground space, cleared and leveled, for drying the prepared peat, and if the peat is formed into bricks at the machine, pallets enough to move the possible output of the machine for several days; room for storing under cover unsold finished product must also be provided.

COST OF PLANT.

The investment necessary for equipping a plant for making machine peat manifestly will be governed by the output of fuel contemplated, the number, size, and kind of buildings which are projected, the amount of equipment to be provided for digging and transportation, and the method of drying—whether on the ground or on racks. If the plan of spreading on the ground be adopted, and the peat be formed into bricks by cross marking the peat layer after it has been spread from movable troughs, much of the cost of tramways, cars, and pallets will be avoided. Although this plan is in use, it has not been fully described, and details will have to be worked out experimentally which will necessarily detract from its value when immediate production must be assured.

ESTIMATED COST OF PLANTS EQUIPPED WITH AMERICAN MACHINERY.

The following tables of costs have been furnished by manufacturers of peat machinery, and are for the season of 1909. The estimated cost of a peat-fuel plant, fully equipped with machinery made in the United States, the fuel to be dried in the air, and the average out-

put to be 50 tons of finished product per day, will be from $20,000 to $25,000, as follows:

Estimated cost of plant for a bog that can not be drained.

1 dipper dredge	$5,000
6 scows, at $250 each	1,500
1 scow excavator and elevator for unloading scows	1,000
1 factory building and power house	2,000
1 boiler (100 horsepower) and engine (75 horsepower) and installation	1,800
1 heater, pump, and fittings	300
1 peat machine and accessories	1,500
Pallets, trucks, and railroad tracks from building to drying grounds	2,500
Drying sheds and racks	3,000
Storage bins and scales	2,500
Miscellaneous machinery, tools, railway side tracks, etc	1,000
Blacksmith and carpenter shops, tools, etc	500
Bog, 100 acres, at $20 per acre	2,000
	24,600

Such a plant could be increased to 100-tons daily capacity at a small additional outlay.

For a bog that is or can be drained, and has a comparatively level bottom, the dredge could be replaced by a forward-end or side continuous-bucket excavator costing $3,500.

Tracks and hopper-dump tram cars for this equipment would cost about the same as scows, and a pump and power to run it would be needed to keep the excavation clear of water.

A plant with an estimated capacity of 25 tons of finished peat fuel per day will cost about one-third less than one of 50 tons capacity.

A portable plant with estimated capacity of 20 tons of finished product per day can be installed for from $5,000 to $7,500. The peat machine, boiler, engine, and digging machinery for this size plant are all installed on a large, broad truck running on a portable wide-gauge track. The costs are divided as follows:

Estimated cost of a portable plant.

1 truck	$1,000
1 20-ton peat machine	1,350
1 mechanical digger	250
1 boiler and engine	750
Pallets, cars, and track	1,500
Miscellaneous tools and equipment	250
1 drainage pump and power	250
	5,350

These estimates are for maximum cost, and can doubtless be reduced in many ways by taking advantage of local conditions. Trackless

self-propelling combined digging, macerating, and spreading machines, capacity from 20 to 75 tons per day, are estimated to cost from $5,000 to $25,000 each. ،

European machinery is generally of simple and strong construction, and in the countries where it is manufactured the cost is low, but the high tariff on machinery and the other charges incidental to its importation into the United States much increase the original price. If German machinery of this type—that which is most often quoted—is sought, the mark (24 cents) must be more than doubled in value and should be reckoned at about 60 cents. On this basis a complete movable plant, operated by steam, and including a traction engine and boiler of from 5 to 8 horsepower; a peat machine with a daily capacity of 30,000 peat bricks (about 15 short tons) per day, elevator belts, and other equipment for transmitting the power, cables, tramcars, and rails for moving the wet peat from the machine to the drying grounds and the dry peat to the storage sheds; and various smaller articles, all of which are listed at a total cost of 8,500 marks, would cost on the cars in New York about $5,000. The peat machine alone with accessories, is quoted at 2,000 marks ($1,200). Besides the machinery, storage sheds and other structures would need to be provided. This class of plant would require hand digging, and 13 people would be necessary to attend the machine, dig and transport the peat, and work on the drying grounds.

A movable plant having double the above capacity and similar but more powerful equipment is listed, exclusive of the buildings, at 14,500 marks ($8,700). This plant requires a force of 16 men to carry on all of the operations, including digging, transporting, drying, and storing the peat.

Among the most recently announced European inventions for making machine peat is one tried in Germany during the summer of 1909 and improved the succeeding year. According to published descriptions, this is self-propelling, requires no tracks for drying grounds, is compactly and simply mounted, and while moving over the surface of the bog, which must be drained, it digs, machines, forms, and delivers the peat as bricks on the drying ground. The entire plant weighs about 3 tons (3,000 kilograms) and requires but one man to operate it. The motor, which has a pulling capacity of 20 tons, may be detached and used to draw cars filled with peat from the drying grounds to the storage bins. The cost at the factory in Germany is 13,000 marks, equal to about $7,500 in New York on the above basis.

PRICE OF THE BOG.

Still another factor to be taken into account is the price of the bog to be utilized. Little discussion has been given this matter because

undrained peat land in the greater part of the United States is held at a very low price per acre, often merely a nominal value being placed upon it. The question may arise, however, as to the maximum figure per acre that could be paid for the bog if the peat was to be dug and manufactured into fuel or other commercial product. If the peat is of good quality and has an average depth of 5 feet, at least 1,000 tons of air-dry peat fuel can presumably be made from each acre. Hence, if $50 per acre is paid, the cost of the raw material will be 5 cents per ton; to this must be added the interest charges on the unused portions of the bog. These charges may be entirely offset by clearing and using a part of the bog for growing certain kinds of crops, as is often done in Germany. Apparently, however, good or even high prices can always be paid for suitable and accessible bogs without imposing too large a charge for raw material upon the finished product.

WORKING CAPITAL.

In planning the whole outlay for a peat-fuel plant, a certain part of the available sum should be reserved as working capital, the proportion to be determined by the probable future needs of the new business and the length of time before a maximum output can be expected from the plant.

PROBABLE OUTPUT FROM A SMALL PLANT.

During the season, from the middle of March to the middle of October, a peat machine of 25 tons daily capacity should make at least 3,000 tons of finished, dry fuel in nearly any part of the United States, and in favorable seasons the output might easily be 500 or 1,000 tons greater. In the south a longer season and larger output could be expected; at the extreme north the season would be shortened somewhat. The production of such a plant could be doubled by working two shifts of men daily.

Such a machine would be much easier to operate at its full capacity, and to provide with full accessory equipment, than one of double the output. Unless the market for the product is known exactly beforehand, planning on a small rather than on a large scale is doubtless much better. The small, well-planned, and thoroughly equipped plant can manifestly be more easily made successful from the outset than can a large and efficient machine, for which necessary accessories are planned in the future, but which, for the present, must be made to run with poor and insufficient equipment.

COST OF MANUFACTURE.

It is generally stated by those who discuss the question that machine peat may be prepared for use at a cost not exceeding $1 per ton. Doubtless this is possible, if only the actual cost of handling

be considered, as in Europe, where the cheapest labor is used in the manufacture of peat; the expense for labor in its preparation is generally stated to be below 75 cents per ton. If, however, the reports of test runs and of carefully managed companies be examined, it will be found that, even in Europe, when the entire cost of production is reckoned and the proper charges for raw material, management, selling, maintenance, interest, etc., are made, the estimated expense is often doubled. Hence it is not improbable that even under favorable conditions the entire cost of making fuel by this method will be more than $1.50 per ton, and will often run as high as $2 or more if all the details of the business are not closely watched. However, if the plants are carefully planned and fully equipped with all necessary machinery, so that slow and inefficient, and hence costly, hand labor is largely eliminated the price of production could probably be materially reduced below the usual European figures. In one instance in the United States, however, a report was made that the entire cost of digging by machinery, drying, and gathering was about 60 cents per ton of product, but the peat was not formed into bricks, but was spread and gathered by machinery. In another instance a cost of less than $1.50 per ton of dry fuel is reported where the peat was dug by hand.

SELLING PRICES.

Eventually the real or supposed value of a product, the supply and demand, the cost of production and transportation, the competition of similar substances, and the extent to which it can be monopolized, are among the factors which settle its price in open market.

At present it is difficult, if not impossible, to predict the prices that machine peat will command in the United States when once it is an established staple in the fuel market. The small quantity that has already been made and sold has been eagerly taken at high prices, often seemingly out of curiosity, but after trial more has been asked for, and no complaints have been made as to the price. A recent report from one of the larger cities stated that a dealer in fuel had asserted that he could sell a number of thousands of tons of air-dry peat bricks at $4.50 per ton if he could get them to sell. Five dollars per ton is frequently mentioned as the retail selling price, even in competition with cheap bituminous coal. In Canada the Department of Mines reported the demand for peat fuel in 1910 to greatly exceed the supply. That such a price will be maintained where the product is to be used for commercial boiler firing or for manufacturing purposes is hardly to be expected, but the wholesale selling price would probably fall to $3 per ton or below. If, however, the cost of production is kept down as it should be and the production of fuel

is large enough, the last-mentioned price offers a good percentage on the investment necessary to make the commodity. Where the manufacturer is so well placed that he can utilize his men and teams during unfavorable weather and after the producing season is over by conducting a retail business, he can command the highest price attainable in his market. This would apparently be good practice, as it would make feasible the employment of some of the men for the entire year.

LENGTH OF OPERATING SEASON.

The estimate of the length of the operating season is based on climatic conditions. The work should be started as early in the season as the frost and water will permit the peat to be dug, and carried on until hard frosts become frequent. In Florida, where the temperature rarely sinks below the freezing point, the winter, being a dry season, is the best time for making peat fuel. As one proceeds northward less and less of the winter season is available, until in northern New England, New York, Michigan, Wisconsin, and Minnesota, peat production, where air drying is used, will be confined to spring and summer—possibly six months, or five north of 45° north latitude. At London, Ontario, the average for several years has been 100 days when peat powder could be gathered from the surface of the bog by a suction collector. The end of the season comes abruptly when frosts are heavy enough to freeze the wet peat bricks, as freezing renders very wet machine peat porous and friable and effectually prevents it from becoming hard and compact.

COMPARISON WITH OTHER INDUSTRIES.

The facts enumerated above form the basis for some of the objections most frequently urged against attempting the manufacture of air-dried machine peat as a profitable business venture. Summarized, they are that the season of manufacture is short; that rainy and damp weather check operations or suspend them entirely; and that the plant and the working force will be employed only a part of the year, and then somewhat irregularly. Manifestly, however, many successful industries are equally handicapped, and just as good reasons exist for discontinuing the beet-sugar industry, lumbering, the harvesting of ice, brickmaking, and other enterprises, most of which require much larger original investment.

THE LABOR QUESTION.

In Europe a considerable part of the labor employed in peat-fuel manufacture comes from near-by farms during periods of slack work, so that the working force is constantly changing as one man or

another returns to his regular occupation.   Such a system may not come into existence in the United States, yet possibly it will, if the need for it arises, and it may provide the labor necessary for carrying on peat-fuel production.   During periods when the weather might be too cold, too moist, or too threatening to permit regular work, a part of the men could be clearing and leveling the surface of the bog, extracting stumps and logs, and constructing necessary ditches.   Even in damp weather wet peat bricks, if protected from actual rain, give up some moisture to the air, so that drying is never actually suspended.   By increasing the area of the drying grounds or the number of racks the making and spreading of peat bricks could go on, even when, otherwise, it would be suspended because the bricks produced could not be cared for.   If this work can be successfully done in the very moist climate of Ireland, of the region around the Baltic Sea, and even of Iceland, it must be possible in the much drier climate of the United States, where not only is the amount of moisture in the air less, but the seasons are longer and the average temperature of the air several degrees higher—all favoring conditions.

ARTIFICIAL DRYING.

A system of artificial drying is an ideal of those who have been working on the problem of the sure production of a large amount of peat fuel in a given time from a single plant.   Even recently the statement has been made that no considerable quantity of peat fuel could be produced in North America unless artificial drying could be assured, and more than one attempt has been and doubtless will be made in the United States to develop plants so planned that the raw wet peat as it is taken from the bog can be put in at one end of a series of machines and turned out at the other as a dry, marketable fuel, the process being continuous and taking but a few hours. Mechanically, the plan presents no great difficulties and may be worked out in a number of different ways, especially if large capital is available.

THE PRACTICAL PROBLEM.

Relative to drying machine peat, the problem to be solved might be said to be how to take the wet bricks from the machine and dry them by artificial heat without handling until the product was ready to be shipped.   A drying chamber of sufficient size and heated to the right temperature would seem to furnish a speedy solution of this problem, but for the following incontestable facts: If the outside of the peat bricks is dried rapidly before the water inside has had a chance to evaporate, and the moisture inside is prevented

from escaping, the bricks shrink, warp, and crack, and become very much more brittle than if dried slowly. The result is an unsatisfactory product. If the drying is permitted to go on slowly the size of the drying chamber must be increased sufficiently to accommodate the entire output for the number of days that the drying is prolonged, and the number of conveyors or pallets and racks needed to support the bricks must be proportionately increased, so that the investment necessary must be much augmented. The greater size of the chamber needed also increases the cost of heating and moving the air by which the drying is accomplished. Solution of the problem is still further complicated by the fact that the peat makes the best product if machined very wet. The bricks seem to be less likely to crack under ordinary conditions of drying and to be harder, denser, and tougher after drying if the peat from which they are formed contains from 80 to 90 per cent of water; in addition grinding goes on more satisfactorily and smoothly, and with less consumption of power. Complications arise, however, from the fact that the higher the percentage of water in the bricks, the more heat is required to dry them, and the limit is soon passed beyond which more heat units are required to dry the peat than the fuel obtained will give if entirely burned under the best attainable conditions.

Stating the case in another form, a pound of good, perfectly dry peat will evaporate 6 pounds of water in a boiler after the boiler-water temperature has been raised to 212° F. This quantity is nearly double that given by good European authorities, but as it is based on a carefully conducted boiler test made at the Government fuel-testing plant at St. Louis, Mo., it may be used as a maximum in order to present the problem as favorably as possible. A ton of peat bricks containing 85 per cent of water consists of 1,700 pounds of water and 300 pounds of completely dry fuel. Therefore, if the water could be evaporated from the peat under as favorable conditions as are found in a boiler, enough fuel would be obtained to convert into steam 100 pounds more water than must be evaporated, or less than 17 pounds; more fuel than this would be needed to raise the temperature of the peat and the contained water to 212° F. It is evident, therefore, that the complete artificial drying of peat by a process that requires a direct consumption of fuel for the purpose must in itself use more heat units than are yielded by the product, and all of the power and labor involved in preparing the bricks and in handling them after drying must be paid for at a loss. If a large proportion of the heat used is waste from other operations, or if the fuel is such as can not be used in any other way, the problem is quite different; but the above statement holds true, and the cost in heat units will be the same, even if they are not used for any other purpose.

WASTE HEAT MUST BE UTILIZED.

It is apparent, therefore, that any process for preparing peat fuel that involves artificially drying to the air-dried state peat containing any considerable percentage of water must be regarded as financially impracticable, unless the heat used is available as a waste product of some other operations. The processes and machinery used for drying products that have a higher selling price than peat fuel, such as heated rollers, vacuum evaporators and presses, are not applicable, since the small margin of profit would all be used up in the costs of operation and maintenance of the complicated and expensive machinery required.

Peat that has been dried by exposure to the air until it contains less than 50 per cent of moisture may possibly be dried for fuel, by artificial heat, on a commercial scale, to the air-dried state, by some of the simpler and more efficient types of driers used in other industries, because the certain and rapid completion of the drying at that stage may offset the cost of the fuel used and of the additional handling and plant required.

It is less practicable to artificially dry peat with a high water content down to 50 or 60 per cent moisture, because the much greater weight of water to be handled and evaporated in proportion to the quantity of product to be recovered requires much more heat than is needed to reduce the moisture from 50 per cent to the air-dried state. In the eastern United States the amount of moisture in completely air-dried peat rarely exceeds 15 per cent and may be as low as 6 or 8 per cent; it varies as the moisture in the air varies.

From the facts given and also from the requirement that all costs in any system of artificial drying must be borne by the product, it is apparent that the problem of artificially drying peat is decidedly complex and can be worked out only by those who have had special training and experience in designing and building drying machinery for similar purposes and fully appreciate the difficulties involved in this class of work. Any plan to be successfully incorporated in machinery for completely freeing freshly dug peat from its high percentage of water must provide for the utilization of large quantities of waste heat or of fuel that has no other economic uses.

WEIGHT OF WATER TO BE EVAPORATED IN DRYING TO VARIOUS PERCENTAGES OF MOISTURE.

The table following shows the weight of water that must be evaporated from a ton of peat as its water content is lowered, by 10 per cent stages, from 90 per cent to 10 per cent.

Weight of water evaporated from a ton of peat as its water content is lowered, by 10 per cent stages, from 90 per cent to 10 per cent.

Percentage of water in peat.	Total dry-peat content.	Water content.	Water evaporated for each 10 per cent reduction.	Residue left for each 10 per cent reduction.	Total amount of water evaporated.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
90	200	1,800. 0	....	2,000. 0	....
80	200	800. 0	1,000. 0	1,000. 0	1,000. 0
70	200	466. 7	333. 3	666. 7	1,333. 3
60	200	300. 0	166. 7	500. 0	1,500. 0
50	200	200. 0	100. 0	400. 0	1,600. 0
40	200	133. 3	66. 7	333. 3	1,666. 7
30	200	85. 7	47. 6	285. 7	1,714. 3
20	200	50. 0	35. 7	250. 0	1,750. 0
10	200	22. 2	27. 8	222. 2	1,777. 8

It will be seen from the above table and the accompanying figure (fig. 1) that eight-ninths of the water in a ton of wet peat is evaporated

WEIGHT OF WATER EVAPORATED FROM 1 TON OF PEAT, POUNDS
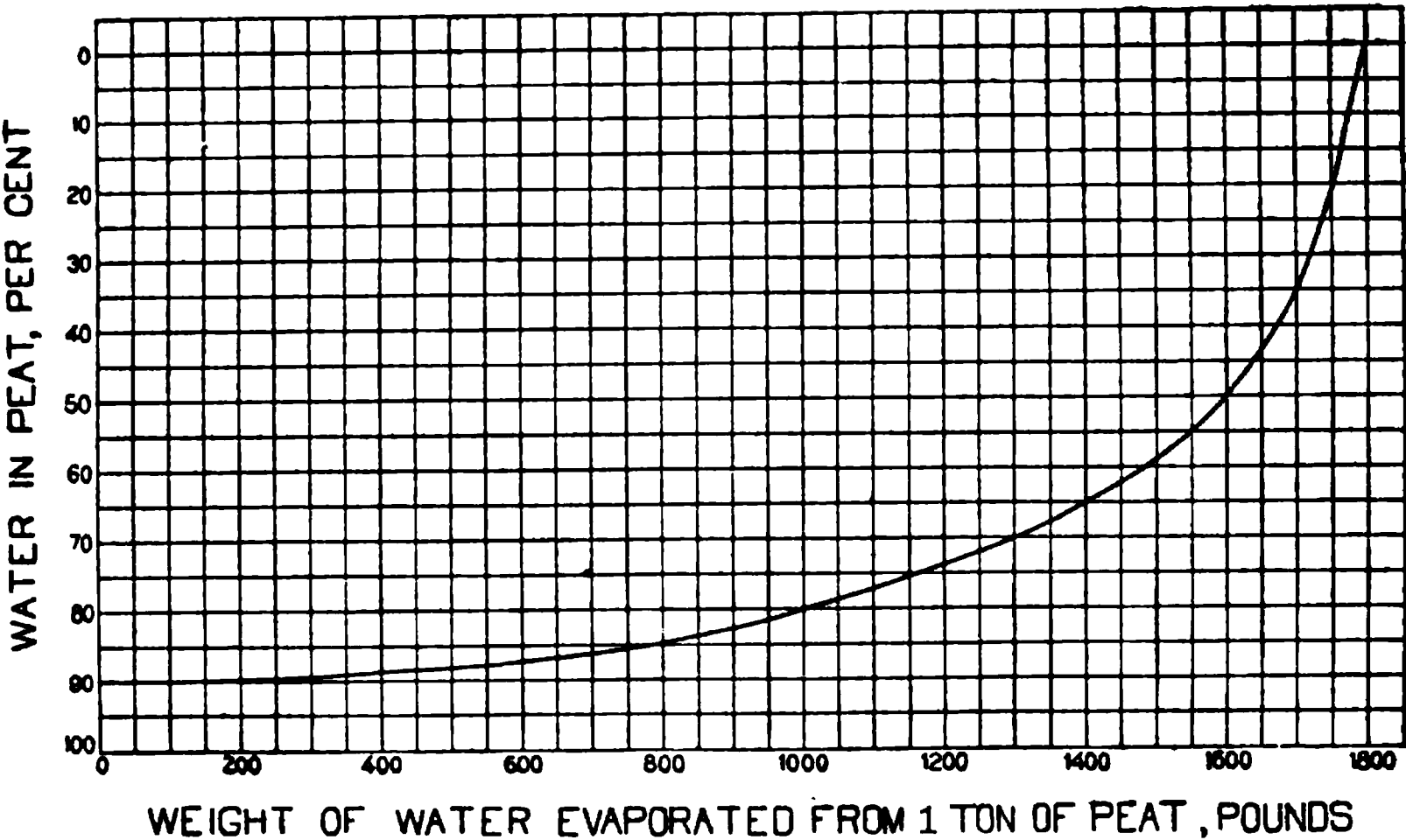
FIGURE 1.—Relation between weight and moisture content of peat.

in reducing the water from 90 per cent to 50 per cent, whereas 1,000 pounds, or five-ninths of the whole, disappears in reducing it from 90 per cent to 80 per cent.

It is manifest, also, that only 250 pounds of peat containing 20 per cent of water will be left as the result of all the processes and labor by which a finished product is made from the ton of wet material.

PEAT POWDER.

There seems to be a much greater possibility of artificially drying peat in the form of powder or small fragments than as machine-formed bricks, because such material can be handled in much smaller space and more rapidly and cheaply than can the bricks. The small

particles also dry more quickly and are not injured by warping, cracking, or by becoming brittle. The peat will dry more rapidly if thoroughly macerated before it is put into the dryer than if it is used as dug.

Although the fundamental factors involved in drying peat by artificial heat are not much more favorable for producing peat powder than peat bricks, the possibility of making the continuous process a commercial success seems considerably greater for the powder than for the bricks. This opinion is held because the cost of equipment can be made considerably less, heat can be applied more directly, and the expenses for handling the product in powdered form can be reduced materially at all stages after it leaves the peat machine. Moreover, the production of dry peat as powder can be assured at any season of the year, as freezing would scarcely injure it at any step of its preparation. In fact, the powdery condition induced in all types of peat by continued freezing and thawing would then be desirable and would naturally be adopted as one of the preliminary stages of the process.

Because peat is readily reduced to a powdered form, has a larger percentage of volatile matter than coal, and burns with a hot flame, it is well adapted for use in powder burners. For this purpose the peat does not need to be crushed as fine as coal because of its more porous structure, which permits the penetration of air, thus insuring complete combustion. It also ignites at a lower temperature than coal.

METHODS AND ADVANTAGES OF USE OF POWDERED FUEL.

It is well known among users of fuel that various types of familiar materials are now burned as powder by the use of specially designed blast burners. Sawdust and powdered coal have been used for a number of years in burners of this type, and most satisfactory reports have been made by the users. The claims are made that the combustion with this form of firing is so complete that there is no black smoke from coal, that the efficiency of the fuel is increased, and that much less attention is required than when firing is done in the ordinary way. The use of powdered coal has passed beyond the experimental stage in Portland cement manufacture and in firing boilers in Europe and the United States. Manufacturers of the improved forms of powder burners claim, for a given type of coal, an increase of from 15 to 20 per cent in efficiency over common grate firing, and facts seem to warrant the claims.

Such burners can be regulated for automatic fuel feed, for furnishing the proper amount of air, and for blowing the fuel into the fire box, where it burns almost exactly like a gas.

EUROPEAN TESTS.

A report of tests made in Sweden in 1907 of peat powder burned in burners of this type is here quoted as cited by Nystrom: [a]

The fuel is very easily ignited in the fire box, but no danger of self-ignition, which is often the case with other powdered and somewhat moist fuels, need be feared.

The combustion of the fuel can be easily regulated so that the ash is always free from any unburned particles of carbon, and so that the carbon and hydrocarbons in the fuel will be at once completely burned to carbon dioxide and water, thus giving the highest temperature with either a weak or a strong oxidizing flame (the former with just enough air for the combustion and the latter with excess of air). The combustion can also be so regulated that a producer gas with only a small percentage of carbon dioxide and of comparatively high temperature (light-red heat) is formed. This hot gas is then carried to the furnace room proper, where it is burned to carbon dioxide and water, there giving the highest temperature. This producer gas can be used for reduction, or in reheating furnaces where the heated material must be kept from oxidation, and then afterwards burned in other furnaces.

The change from oxidizing to reducing flame, or vice versa, can be very easily and quickly made.

The quantity of the fuel and the required amount of air can at any time and in either of the above cases be exactly regulated as required, and in case no change is required no attendance is necessary after the valves are once regulated [in the special type of burner examined].

The powder gives the highest temperature which can be employed in furnaces with a considerably less consumption than can be obtained with any other of the solid fuels, and it can be used for the melting of glass, cast iron, steel, soft iron, and other metals. The right temperature is more quickly obtained through the combustion of the powder than by the older methods.

Furnaces for using this fuel are considerably cheaper to erect than those designed for the use of other fuels.

Capt. Ernst Wallgren, chief peat engineer of the Swedish Government, in an official report of tests made by him in 1910 and preceding years at the Ekelund plant at Bäck, Sweden, states in substance:

(1) Peat powder could be produced at this factory in commercial quantities if the plant were run for a full season at its present estimated annual capacity of 10,000 metric tons at a maximum cost of 8.50 kroner ($2.30) a metric ton (2,204 pounds), all charges included.

(2) This cost could be reduced by increasing the size of the plant and the output or by making contemplated changes in equipment.

(3) The peat powder when burned by the method used at Bäck was equal in fuel value to the best English coal, ton for ton.

(4) This discovery makes Sweden independent of other countries for fuel supplies for industrial uses.

These reports and those that have come independently from Canada,[b] where peat powder is used to a limited extent for boiler firing, show clearly that this type of fuel is an especially desirable one, which needs more extended and careful examination, so that it may

[a] Nystrom, E., Peat and lignite; their manufacture and uses in Europe, Canada Department of Mines, Mines Branch, 1908, pp. 171-172.

[b] See also Can. Dept. Mines, Mines Branch, Bull. No. 4, 2d ed., 1910, pp. 19 and 31 to 44.

have a greater use for cement manufacture and steam production generally if it proves to be as valuable as the reports indicate. The peat for making peat powder by the system mentioned (Ekelund's) is dug, machined, spread on the bog, cut into bricks, and dried by exposure to the air to 50 per cent water content. The bricks are then crushed and the powder dried in drying furnaces.

SPECIAL GATHERING SYSTEMS.

For the preparation of peat in the powdered form a system of gathering the peat as air-dried powder by a special type of collector has been developed in Canada. The cleared and smooth surface of the bog is lightly stirred by harrowing, and after a few hours' exposure to the wind and sun the thin layer becomes dried to 30 per cent or less of moisture. The dry particles are then gathered by a pneumatic collector operated on the same principle as the exhaust carpet cleaners that are now so generally used. The collector is operated electrically and runs on rails, which can be moved whenever necessary. The peat, with its low percentage of moisture, is taken to the plant in the cars that receive it from the collector; there it is screened and its moisture content still further lowered by artificial drying, after which the powder is ready for use. It is shipped in bags and may be stored without deteriorating. The statement is made that each collector on a favorable day will gather from 40 to 50 tons of air-dried peat powder from a drained and well-prepared bog.

Although this method of drying peat powder is manifestly open to the same objection as any form of drying out of doors, it is equally clear that by increasing the number of collectors and the area of the surface from which the air-dried material can be gathered in favorable weather great quantities of air-dried powder may be stored for complete drying during rainy days or during the winter, especially if the peat is produced in quantities.[a]

This dry material could be stored either in permanent and strong storage bins, constructed for the purpose, or in large stock piles,

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[a] Another system of producing air-dry peat powder was invented in Canada. It is now in use there at the peat-briquet plant of the inventor and in the United States at two factories producing peat for fertilizer uses. The simple and efficient machinery used consists of three separate machines—a digger and spreader, a scraper, and a collector. Each of these is mounted on broad roller wheels and driven by electric motors, to which current is supplied from a central generator through trailing, insulated wires.

The digger and spreader, although mounted and working together are distinct machines. The digger, a plow-like disk revolving at one side of the machine, cuts the peat to a depth of 12 to 18 inches and delivers it to a belt conveyor. This draws it across the front of the machine and up a chute projecting from the side opposite the digging disk. At the upper end of the chute is a rapidly revolving propeller-shaped fan, which tears the peat into bits and scatters it broadcast over the surface of the bog, which is stripped of all vegetation before being used as drying ground. The powdered peat dries in a few hours and is scraped into windrows by the scraper which at the same time rolls the surface. thus preparing it for the next spreading. The windrows are made near portable tramways at the sides of the drying fields, and the peat is mechanically loaded on tram cars by a simple loading machine and drawn by an electric locomotive to the storage piles or sheds, after which drying is completed by artificial heat. This system must be used on dry drained bogs.

which, although they might become wet and frozen on the outside, would remain dry and free from frost a short distance below the surface, because penetration of the mass by either water or cold would be very slow, owing to the insulating and nonabsorbent qualities of the material.

COST OF EQUIPMENT.

The cost of erecting and fitting out a plant for making peat powder is estimated by the inventor of the Swedish process mentioned to be about $100,000 for a plant having an output of 20,000 tons per year. This amount includes the cost of the peat deposit; the cost of manufacture is given as less than $2.35 per ton.

No figures are available for publication regarding the cost of a factory using the Canadian processes and equipment, but the cost of production is said to be less than $1.50 per ton. The process obviously can be used only during the warmer months of the year.

TYPES OF DRYING MACHINES.

In Europe, lignite, or brown coal, is dried by artificial heat before it is briquetted. Two types of driers have been developed and are now used for this purpose—the steam plate and the rotary, the latter being the more recent and the more efficient.

In the steam-plate system the powdered lignite is dried on hollow cast-iron plates heated by steam from the engines or from the briquetting presses of the plant. The plates are 16.5 feet in diameter and are supported one above the other in a series of twenty or more, with intervening spaces. A central shaft bears a series of arms which, when the shaft is turned, constantly stir the material that is being dried. Provision is made for hastening the drying by changing the air as often as it becomes saturated with moisture. In such driers the water of the lignite is reduced from 30 to 40 per cent or more to 12 to 18 per cent, which is the content most suitable for briquetting this material.

In the best European type of rotary drier the essential part is a large boiler-plate cylinder inclined at an angle of 7°, supported by and turned on trunnions. A large number of 4-inch tubes run from end to end of the cylinder and through these the material to be dried passes. It is fed in at the upper end and dried by the heat of the steam that is turned through the trunnions into the space around the tubes. The steam is supplied from the exhaust from the engines and briquetting presses. The powder dries during its passage through the tubes, and is mixed, as the cylinder revolves, by cleats or baffle-irons fastened to the inside of the tubes. Such driers have been used to some extent for drying peat, and if the moisture content were not too high could be used in the production of peat powder for fuel, for briquetting, or for fertilizer filler.

In the United States a number of novel machines for drying peat have been invented and installed in factories for the manufacture of peat briquets, but as none of the plants are now operating, the machines seemingly failed to do what was expected of them. In the manufacture of peat powder for fertilizer filler, however, driers of the rotary type, originally designed for drying clay, shale, and materials used in brick, cement, and fertilizer making before they are ground, have been used for some years to complete the drying of peat that has been partly air dried.

Two forms of rotary driers are used for drying peat in the United States—single-shell and double-shell. Both types are long cylindrical tubes made of iron or steel plates bolted together as in boiler construction. The tubes vary in length and diameter according to their estimated capacity for drying. They are mounted in a slightly inclined position, and are supported and rotated by friction rollers or geared wheels placed near either end.

At the higher or inlet end, if single-shell driers, the cylinder is generally placed directly against the open end of the combustion chamber of a furnace, and the lower end opens directly into a brick chamber that is closely connected with the smokestack. The cylinder is therefore a part of the flue through which the products of combustion pass from the furnace to the air. Usually there is an exhaust or a blowing fan to increase the combustion or hasten the passage of hot gases through the tube.

Narrow iron shelves, projecting at an angle inward and running, either spirally or otherwise, the entire length of the tube, are securely bolted to the inside of the shell. These shelves carry the peat from the bottom to the top of the cylinder and allow it to fall again to the bottom through the current of heated gases and air, thus assuring more rapid and thorough drying than would be possible if the inside of the cylinder were smooth.

The material to be dried enters at the higher end of the drier at the hottest part and is slowly carried to the lower and cool end by the rotation. It ultimately falls into the receiving chamber as a dry powder. Peat so dried contains less than 10 per cent of moisture.

The efficiency of such a drier depends on the relationship between the quantity of water to be evaporated and the quantity of heat units which must be made available to convert the water into vapor. To attain the highest efficiency, the heat generated in the furnace should all be absorbed by the material that is being dried, and the gases and air passing through the drier should leave it cold.

In practice, however, driers are often much overheated, which results in great losses of heat through radiation from the overheated shell and the high temperature of the gases leaving the tube. The remedy is to use longer cylinders of larger diameter, and to reduce

the moisture content of the peat as much as possible by air drying before putting it in the drier.

A double-shell drier, as the name implies, has two cylinders, one securely fastened concentrically inside the other, with a space between them. The hot gases from a furnace enter the inner tube of the drier at one end. In the same end the material to be dried is placed in the chamber between the inner and outer shells. After traversing the length of the inner tube the gases enter and pass through the outer one and are deprived of the rest of their heat by contact with the substance being dried. The circulation is maintained by exhaust fans at the outlet end. As the heated gases pass twice through the length of the cylinder, more time is allowed them to give up their heat to the substance being dried. A double-tube drier should, therefore, be more efficient, and give a greater amount of dry product per unit of fuel consumed than a single-tube drier.

As the price obtained for the product of the driers is considerably more than that which could be obtained for the same material if it were to be used as fuel, a somewhat greater outlay can be borne in preparing it for market; but experience has demonstrated, as would be expected, that the more the water in peat is reduced before putting the peat into the drier the lower the cost of production becomes. Presumably, therefore, by using some of the types of driers developed for drying tankage, garbage, and other similar materials, peat, in the form of a powder that has been partly air dried can ! : dried to a moisture content of from 10 to 15 per cent with profit, especially if a part or all of the heat used be derived from stack gase.' or exhaust steam.

PEAT BRIQUETS.

ADVANTAGES OF BRIQUETTING.

Manifestly peat powder can not be burned economically in an ordinary fire box or stove, because it packs so that no air can get through it, or it falls through the grates if stirred. Such fuel is also open to the objections that are urged against other forms of peat fuel, and is costly to transport as compared with coal. To avoid these difficulties the proposal has been made to shape the dry powder into briquets by the use of specially designed briquetting presses. In Europe, where peat is commonly used, and where for a considerable time lignite and poor grades of coal have been put on the market in briquetted form, and have found ready and constantly increasing sales, it is not surprising that peat should have been briquetted at an early date.

PROPERTIES.

Peat, when briquetted, makes a most attractive type of fuel, as the briquets are uniform in size, may be of cylindrical, ovoid, pris-

matic, pillow, or other shape, and often have a highly glazed black surface. The briquets are clean to handle; they are also compact and dense, so that they occupy less space, and are more easily transported and stored than the same weight of the same peat could be if in any of the other forms described. They burn less rapidly than cut or machine peat, and hence give less trouble in firing for power production than do other kinds of peat fuel.

It has been pointed out, however, that peat briquets are likely to crack and crumble when handled roughly, and to break down in the fire into a powder, whereas machine-peat bricks burn like a piece of good coal, or wood, without falling apart. The briquets are also easily wet by rain, and are quickly disintegrated by exposure to storms; therefore they must be stored under cover and shipped by rail in weatherproof cars.

METHODS OF MANUFACTURE.

In the parts of Europe where peat briquets are made the peat is cut or dug from the bog and is allowed to dry in the air until the water is reduced to about 40 per cent. The peat is then powdered and dried artificially to about 15 per cent moisture, after which it is briquetted or stored for future briquetting.

The Canadian method of drying peat on the surface of the bog in a thin layer and picking up the dry material at frequent intervals with a vacuum dust collector does away with most of the cost of drying and subsequent handling, so that after a brief exposure to artificial heat it can be satisfactorily briquetted. The process was primarily designed by its inventors to produce at the lowest cost air-dried peat for making briquets.

TYPES OF PRESSES.

The essential part of a plant for making peat briquets is the briquetting press. Such presses are of two general types—the open and the closed mold. In the open-mold type the dry peat powder is introduced into a straight tube, or mold, of circular or other shaped cross section, and compressed by a tightly fitting piston that exerts a pressure of from 18,000 to 30,000 pounds per square inch. Sufficient resistance is offered by the friction of the peat on the sides of the tube to press it into a solid block or briquet, while at the same time the air is forced from the peat. With each stroke of the piston a new charge of peat enters the mold and a finished briquet leaves the outlet end; the briquets already made act as a cushion and, in fact, form the bottom of the mold. The friction is sufficient in presses constructed on this principle to raise the temperature of the mass enough to release some of the tarry compounds of the peat,

and these cover the sides of the briquets with a highly polished glaze. A chief objection to this form of press is said to be that the constant heating and friction produce great wear on the molds, and the plates forming them must be removed every few days and reground, so that after a comparatively short life they have to be renewed.

The number of briquets that can be made with such a machine manifestly depends upon the number of strokes of the plunger to the minute. For briquetting lignite, this may be as low as 80 or as high as 130; thus the number of briquets made in a minute lies between these limits. The output of peat briquets is usually about 100 a minute, because the peat powder is sometimes blown from the mold if the press is run at greater speed.

In briquetting presses of the closed-mold type various forms of rollers and plates, or plungers and wheels or plates, or even special forms of crown wheels, have been employed for the two halves or parts of the molds. The advantage claimed for presses of this type is their greater rapidity and durability, but mechanical difficulties are encountered in getting sufficient pressure to make solid briquets and in keeping the two halves of the mold in exact adjustment. This form of press is sometimes used when a binder of pitch or other resinous or tarry matter is used to cement the particles of fuel together to make the briquets less breakable when handled or burned.

European briquetting presses of the open-mold type are made in three sizes—a small size, turning out from 16.5 to 22 tons of finished briquets in 24 hours; a medium size, having a capacity of 33 to 44 tons in 24 hours; and a large size, which makes from 44 to 55 tons in 24 hours.

To produce a ton of peat briquets costs considerably more than to produce a ton of machine peat because of the greater power required, the artificial drying, and the additional expenses for stronger buildings and more complicated and powerful machinery.

TREATMENT OF PEAT PRELIMINARY TO BRIQUETTING.

All European factories for making peat briquets are reported to use cut peat of the more compact kinds as raw material, because it can be ground more quickly and thoroughly than the tougher machine peat. The peat is treated exactly as if it were to be used as the cut product, until the water is reduced by evaporation to 40 or 50 per cent; it is then taken to the plant and ground while still moist so as to avoid the dust and resistance to the mill which result from grinding with less water. It is then screened. The drying is finished in a dryer, and the dry powder is either briquetted immediately or stored. If ground when too dry, considerable loss occurs from the finer particles flying about as dust, the presence of which in air is annoying and dangerous to the workman, and under certain conditions may cause disastrous

explosions. The dry peat is also hard to grind and rapidly wears the milling machinery.

There is no record either in Europe or America of a successful plant for making peat briquets by a continuous process that dries the peat wholly by artificial heat.

COST OF PLANTS.

European briquetting presses of 50 tons capacity in 24 hours, which is the size most often considered, need engines of about 100 horsepower, operated by high-pressure steam; in the best equipped European plants the steam is superheated to about 665° F. and the boiler pressure is carried at about 150 pounds. The exhaust steam from the engines is used in the driers, at about 30 pounds pressure, and is returned to the boilers after condensation under about the same pressure.

A briquetting plant, fully equipped with the best types of German machinery, including a drier, will cost two to three times as much as a plant for making cut and machine peat, even if only a single press with a capacity of about 50 tons per day is contemplated.

At least three distinct presses for briquetting peat have been invented and tried on a factory scale in Canada. Two are of the closed-mold type, although working on very different principles; the third employs an open mold. The peat used for these plants was dried as much as possible on the surface of the bog, but the final drying was done in specially designed rotary driers.

The essential details of these plants have been described by Nystrom.[a] Of these plants only one was operated in 1908, and no figures as to the cost of installation or of the production of the briquets are available. Two of them made a small output in 1910. Several forms of presses of American construction for briquetting coal and lignite, and some designed for peat, have been developed and are on the market, and probably these could be installed at somewhat lower cost than any which have been made abroad. It is doubtful, however, whether a bog can be purchased, proper buildings erected for housing the machinery and the finished briquets, and the necessary machinery bought for digging, grinding, drying, and briquetting the peat for an output of about 50 tons of briquets each 24 hours for less than $60,000 to $75,000, although estimates as low as $35,000 have been made based on untried machinery.

The plan of drying the peat upon the surface of the bog and gathering it as a dry powder with a small amount of water, because a part of the cost of preparing the peat for briquetting is thus eliminated, should reduce the primary cost of the plant by a certain amount. It

is questionable, however, whether the cost of collecting machines and their installation would not be almost as great as that of the rotary driers which they would in part displace. Their operation by electric power might prove to be nearly as expensive as that of steam driers utilizing waste steam.

The operation of the briquetting part of a plant during the winter could be made possible by operating a number of the collecting machines during the favorable months of the drying season and storing in stock piles or storage bins the excess of dry peat as it was taken from the surface of the bog. If storage under cover were adopted, the construction of the necessary buildings would be an added charge.

The following statement, which shows the cost of a briquetting plant with an estimated output of 50 tons of peat briquets per day, is quoted from an estimate furnished by Mr. F. H. Mason,[a] when United States consul general in Berlin, Germany:

Buildings	$14,280
Machinery	17,850
Steam engines and fixtures	3,570
Tramways	3,570
	39,270

These figures are approximate only and will have to be considerably modified to meet present conditions.

The American agent of one of the leading German builders of briquetting plants furnished the following estimates for a peat briquetting plant having an estimated capacity of 40,000 kilograms (about 44 short tons) of finished briquets in 24 hours:

The complete mechanical plant, which costs 201,000 marks ($48,240) in Germany, includes two large steam boilers, necessary engines, conveyers, elevators, electrical generators and motors, a rotary drier, a powerful press, sieves, and the numerous other items of machinery needed to carry on successfully the rather complicated processes that seem required to produce marketable peat briquets steadily and in quantity. The duties, trans-Atlanitc freight, and other charges to which foreign machinery importations are subject more than double the list prices, so that the mark must be reckoned as equivalent to 60 cents; thus the estimated cost of this machinery becomes about $120,000 when delivered to the American purchaser on the cars in New York.

Many of the items included in this list could doubtless be replaced at a less cost by those of American manufacture. To successfully install the briquetting press and drier, however, would require the importation of some of the other machinery designed to accompany

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them, so that it is probable that a briquetting plant of the capacity given above could scarcely be equipped for less than $70,000 to $75,000. To this amount must be added the cost of special digging machinery, buildings, railroad sidings, etc., which would mean a total investment probably exceeding $100,000.

COMPARATIVE COST OF BRIQUETS AND MACHINE PEAT.

The cost per ton of making peat briquets must of necessity be greater than that of making machine peat, because a larger investment in plant is needed and this involves larger charges for interest and depreciation. The more complicated machinery requires more skillful and better-paid men, and the machinery requires greater power, and therefore a greater consumption of fuel. The wear on the briquetting presses is excessive, which makes the cost of maintenance high in comparison with that of the more simple peat machine, and the cost of artificial drying, of grinding the peat, and of briquetting must also be taken into consideration. In view of all these factors, and the added cost of digging and partially air drying the peat and of getting it to the briquetting machinery, peat briquets can probably not be made under American conditions with any machinery now in use in Europe at much less than $3 per ton, and conditions would have to be excellent if this price were not exceeded.

What can be done with peat briquetting machinery and plants of American design and construction now in process of development or installation can not be predicted at this time.

COMPARATIVE FUEL EFFICIENCY.

Naturally, the inquiry will be made whether the added expense of equipment and the greater cost of making peat briquets is justified by a corresponding increase in the efficiency of the fuel. Seemingly it is not, because the cost of production is at least one-third greater than for machine peat, whereas, according to Nystrom,[a] the heating value is increased only about 15 per cent. Actual analyses of peat from the same deposit at Black Lake, N. Y., and prepared in different ways, are given below. The samples were taken at random from considerable quantities of similar material which had been given identical treatment, but possibly gathered at different times; that is, the samples were not prepared especially for these analyses.

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[a] Nystrom, E., op. cit., pp. 147-148.

Analyses of peat to show the effect of method of preparation on heating value of a given peat.

Lab. No.	Character of fuel.	Mois-ture.	Volatile com-bustible.	Fixed carbon.	Ash.	Sul-phur.	Heating value.	
							Calories.	B. t. u.
6436	Raw peat:							
	Air dried	8.68	50.92	23.79	16.61	0.99	4,179	7,522
	Moisture free		55.77	26.04	18.19	1.08	4,576	8,237
6394	Machine peat:							
	Air dried	9.33	49.85	23.35	17.47	.89	4,055	7,299
	Moisture free		54.97	25.77	19.26	.98	4,472	8,050
6392	Dry powder before briquetting:							
	Air dried	7.37	52.03	22.74	17.86	.96	4,102	7,384
	Moisture free		56.17	24.53	19.30	1.03	4,428	7,971
6395	Briquetted steam-dried peat:							
	Air dried	8.00	52.19	22.44	17.37	1.16	4,193	7,547
	Moisture free		56.73	24.39	18.88	1.27	4,557	8,203

Average heating value of dry peat, 8,115 B. t. u.

This table indicates that the differences in the number of heat units obtained from the different samples are slight, and it is difficult to see that any appreciable change has been made by the various kinds of treatment. Equal variations might occur in the same number of samples of peat collected from a single stratum at the same time but analyzed separately. Therefore, except for the greater compactness and hardness obtained, there is no justification for incurring the cost of briquetting. However, a larger series of more carefully collected samples may show greater variation than is here indicated; or if drying or briquetting at high temperatures is adopted so that some of the lighter volatile combustibles are driven from the peat, a somewhat higher thermal value may be obtained. Clearly, however, briquetting as a rule increases the number of heat units per unit of volume and not per unit of weight; that is, the peat is made more compact, so that it can be transported and stored in smaller space and burned in smaller fire boxes than if prepared in other ways. Whether the advantages thus obtained are sufficient to justify the additional costs of building a plant and of making the briquets on a commercial scale must be demonstrated by actual operations.

ELECTRIC PROCESSES FOR DRYING PEAT.

The fundamental plan of electric processes for drying peat is to pass electric currents, either direct or alternating, through the wet peat, with the idea of liberating the water by breaking up the cells and fibers of the vegetable remains in the peat. The most thoroughly advertised of these processes was one developed in England and embodied in two plants, one at Kilberry, near Athy, in the county of Kildare, Ireland, and the other near Eaton Rapids, Mich. Although both of these plants were well supported by capital and equipped

with unusual thoroughness, both were complete failures. The peat was dug by a "grab" dredge or shovel and dumped into cars which took it to the factory. Here it was thrown on an endless belt, by which it was elevated to the hopper of what was called by the inventor a "hydro-extractor," a form of press that squeezed out part of the water. . From the base of the hydro-extractor the peat passed between the plates of the electrolyzer, and a powerful alternating electric current was passed into it for some time. The peat thus electrolyzed was forced into another hydro-extractor, or eliminator, placed below the electrolyzer, and in this the water liberated by the passage of the electric current was forced out. From this press it was carried by a bucket conveyor to the top of a large slab, where it was crushed by four heavy rollers, each weighing a ton, and thence the crushed, electrified, and pressed peat passed to a molding machine with six dies, which formed it into bricks and deposited these on a revolving table. The bricks were then removed from the table by a scraper to cars which carried them to drying sheds, where the drying was finished by contact with the air as in ordinary air drying.

The material thus obtained was called electro-peat coal, which, like many of the other names applied to peat products, was a misnomer, because in reality it was no different from, if as good as, ordinary machine peat, and in no way resembled coal.

The more extensively advertised electric processes seemingly have been based upon the supposition that the electric discharge into the wet peat would burst the cells of the plant remains in it, and the water could then be quickly pressed out; but such a result does not seem to have been attained to an extent warranting the treatment. The theoretical consideration of the matter leads to the conclusion that no such effect can be produced, because the differences between the conductivity of the water and of the saturated vegetable matter constituting the walls of the cells is very slight, if any exists, and upon such differences the supposed effectiveness of the electric charge must be based. The heat energy derived by converting the electric energy through the resistance offered by the water and peat is obtained at a cost from ten to fifteen times as great as by direct firing.

WET CARBONIZATION.

UNDERLYING PRINCIPLES.

In 1904 and the following years Dr. M. Ekenberg, of London, England, conducted a lengthy series of experiments on what has been called the "wet carbonization" of peat. As the term indicates, the wet peat is subjected to temperatures slightly above 300° F. (150°–155° C.), which drive off a part of the lighter hydrocarbons if the heated mass be kept at ordinary pressure. During the heating, how-

ever, a pressure of about 150 pounds to the square inch is maintained by the pump which forces the wet peat into the carbonizing apparatus, so that the process really consists of superheating wet peat in a closed receptacle under pressure of about 10 atmospheres. Such pressure is quite enough to prevent any steam from forming at the temperature at which heating is carried on, so that there is no loss of heat units from this source and no volatilization of the hydrocarbon compounds of the peat.

PROCESS OF TREATMENT.

After digging, the wet peat is thoroughly macerated in a special form of peat machine located on the bog. The machine delivers the peat as a finely divided pulp to dumping cars, which convey it to the plant, and there it is stored in a large tank until used.

The wet-carbonizing furnace, the essential feature of the process as it was developed in an experimental plant in Sweden, consists of a series of 52 iron pipes, some 36 feet long, all heated from a fire box at one end of the series. Each tube is double; the smaller inner tube has on its outside a screw flange which, when the tube is turned, moves the peat through the space between the tubes. The inner tube is open at both ends, and at its free end is connected with the corresponding ends of all of the rest of the series. Each of the larger outer tubes is connected with a common inlet, through which the wet peat is forced by a specially designed pump. At the end opposite the inlet the large tube projects into the fire box and is exposed for half its length to the direct heat of the fire.

The peat pumped into the common inlet is forced through the outer tubes by the pressure of the pump and the screw flanges of the inner revolving tube, and then, wet and hot, into the open end of the inner tubes and through these to the outlet.

The economy of heat effected by having only that half of the length of the tubes heated that is remote from the inlet is manifest when one considers that the cool material coming into the outer tube takes the heat from the hot material going out through the inner tube. Thus the cool material is hot when it reaches the directly heated part of the system, and the outgoing material gives up a considerable portion of its heat before it reaches the outlet.

From the carbonizer the peat is conveyed to a special type of filter press, which reduces the water to about 55 per cent, according to Nystrom, or, according to later reports, to about 10 per cent, from the original 85 to 90 per cent. The material from the filter press is dried artificially and briquetted.

PROPERTIES OF PEAT AFTER TREATMENT.

The peat becomes blackened, loses its structural peculiarities, becomes fine grained, and, it is stated, readily gives up under moderate

pressure a considerably larger percentage of water than untreated peat. It is reported that a form of coking takes place, the extent of which is governed by the temperature used during the treatment, the use of higher temperatures giving more complete carbonization. If this is true, as the blackening of the peat would indicate, apparently the matter driven off must be absorbed either by the peat itself or by the water which it contains, as no gases are developed during the process. It is evident, however, that at the temperature reported (300° F.) the process of coking is not carried very far, because only at considerably higher temperatures are volatile carbonaceous matters driven off by dry distillation.

The exact nature of the changes that take place is immaterial to this discussion, however, since the important fact is that a definite change is effected by the treatment which makes possible the quick drying of the peat by artificial heat and pressure. From available reports the process, when it is fully developed, will seemingly be commercially useful and will enable those who adopt it not only to extend the season of operations to early winter, but to produce very hard, heavy, and black briquets closely resembling coal in appearance and, volume for volume, having about the same fuel value as bituminous coal of ordinary grades.

COST OF BRIQUETS BY THIS PROCESS.

The cost of manufacture, including all charges for digging and grinding the peat and transporting it to the factory, and for carbonizing, drying, and briqueting, interest, depreciation, and administration, is estimated, from the results obtained at the experimental plant in Sweden, to be $2 to $2.25 a ton of finished briquets. The smaller cost is estimated for an output of 20,000 to 30,000 tons in a year of about 200 working days. The English company owning the patents covering the processes and machinery estimates that the briquets can be made in a factory turning out 100 tons of briquets a day, under European labor conditions, for about $1.50 a ton, after the machinery now being experimented with shall have been fully perfected.

COST OF PLANT.

The cost of a plant fully equipped with briqueting presses, carbonizers, and all other accessories is estimated by the inventor at about $160,000; or, if production is to be 30,000 tons of briquets a year, at about $225,000, at European prices for machinery, structural work, and labor.

CLAIMS OF INVENTOR.

The inventor claims for this method of treatment that—

(1) The manufacture is independent of weather conditions.

(2) The work can be carried on equally well night and day.

(3) Undrained bogs can be worked without difficulty.

(4) All the processes of treatment may be completed and the briquets made in two hours after the peat is dug.

(5) The fuel produced is always of the same quality. The water content may be as low as desired.

(6) The number of men required for a plant with an output of 100 tons a day is small compared with that needed for the same output of machine peat, as only from 18 to 24 men are needed, chiefly to watch and care for the machinery.

(7) Since the process is continuous and may be carried on independent of weather conditions, an abundant supply of labor can be had without difficulty, because the men will be assured steady work.

PROSPECTIVE VALUE OF PROCESS.

The various unbiased reports which have been made concerning this way of treating peat lead to the conclusion that it is one of the most promising that has yet been discovered, and if the treatment and machinery are not too costly it may yet become the basis of a successful continuous-process, peat-drying, and briquetting industry. No reports have yet appeared, however, showing that the method has been applied in a successful commercial plant, and for that reason the process must still be considered as experimental, some of the important details needing development and embodiment in machinery.

FUEL PRODUCTS DERIVED FROM THE DISTILLATION OF PEAT.

PEAT CHARCOAL.

Early in the eighteenth century a crude process of making charcoal from peat was in use in several European countries, and presumably cut peat was made into charcoal at an earlier date in districts where wood was scarce.

The simplest way of making charcoal from peat is that of the charcoal burners of Europe, who made a circular, dome-shaped heap by piling cut-peat bricks in regular courses around a pole, at the base of which a small quantity of dry fuel was placed to start combustion. A fluelike space, through which the dry fuel was ignited and air was admitted, led to the outside of the heap. A small space around the central pole formed a chimney for gas and smoke as needed, and various inlets for air were made through the sides of the structure. The heap of bricks was covered with a layer of brush, outside of which was placed a layer of earth, varying in thickness gradually from about 1 foot at the bottom to half as much at the top.

After the fire was well started the chimney opening in the top of the heap was closed, and the combustion was then carefully watched by a man of experience who regulated the supply of air so

as to prevent too complete combustion and yet keep the fire from going out. When the coking was judged to be complete, all openings were closed by damp earth, the fire was allowed to die out, and the mass was permitted to cool thoroughly before the heap was opened. The yield of charcoal recovered by this method was generally from 30 to 40 per cent of the original weight of the peat.

In some parts of Europe the peat was piled in long, narrow pits about 1 yard wide and 20 yards long. The heaps so made were converted into charcoal in much the same manner as were the smaller ones. In Sweden, peat charcoal was made to some extent in kilns of iron or masonry. Peat was piled in these to a considerable height above the mouth and a fire started at the bottom and allowed to burn until the mass had settled down to the level of the top, when a layer of green rushes or brush was spread over the mouth and quickly covered with wet clay. This brought the combustion to an end and after the kiln was cooled the charcoal was removed.

PEAT COKE.

EARLY ATTEMPTS AT MANUFACTURE.

The crude method of making charcoal from peat piled in heaps was improved as early as the first half of the eighteenth century, when Lange developed a special furnace consisting of a vertical cylindrical iron furnace, conical at the top, and partly closed at the bottom by an iron plate in which was a barred opening. The plate rested on a stone base in which was an arch or fire box closed by a tightly fitting iron door.

The furnace was filled from the top with peat bricks and combustion was started in the mass by building a fire in the stone fire box. When the lower part of the peat was burning freely, the door was closed and the fire allowed to smolder until the peat was coked; then the furnace was filled to the top again and the process of burning continued. After a number of chargings, the furnace became filled with burning coke. Then the opening was closed and all air was shut off until the coke was cold. This furnace gave a small output of porous and friable coke and after a time its use was abandoned.

In still another type of furnace, developed in Germany, the firing was done from the top, the gases developed during coking being drawn down through the mass of peat and out of the furnace by pumps attached to pipes leading from the bottom of the furnace. The purpose of this arrangement was to prevent loss from crushing, because by its use the brittle charcoal was formed above the undecomposed peat, and did not have to bear the weight of the latter.

None of these ways of making coke and charcoal from peat proved very remunerative, however, in spite of every care to reduce waste. The cost of production measured by fuel consumed in making the

coke was large and the output was small and generally of unsatisfactory quality.

The fact that good peat coke or charcoal had all of the desirable qualities of wood charcoal and fully as high calorific value made it a useful and salable fuel, especially as wood charcoal became less abundant and more costly.

DRY DISTILLATION IN RETORTS.

The facts cited above led to continued experimentation, and as early as 1786 coke was produced by dry distillation of peat in retorts heated from the outside; the heavier volatile hydrocarbon compounds like tar were condensed and saved and the noncondensing gases were used for fuel or illuminating purposes.

From 1786 until the present time many European inventors and some Americans have worked upon processes for coking peat in retorts with more or less complete recovery of the useful chemical substances that by condensation and redistillation at different temperatures may be derived from the liquid products of the decomposition of the peat. These efforts have been concentrated upon making hard, firm peat coke which should be at least as good as good charcoal, or even as hard as coke made from coal, and upon saving all of the volatile products that could be made into marketable chemical compounds without too great expense.

THE ZIEGLER PEAT-COKING PROCESS.

In the last decade of the nineteenth century a method of coking peat in retorts was worked out and patented by Dr. Martin Ziegler, a German chemist and inventor. In this method the permanent gases derived from the dry distillation of peat are used for heating the retorts in which the coking is done, and for other operations about the plant. The system also provides for the use of the same retorts continuously, and for the recovery in a most practical way of all marketable chemical compounds as by-products. Three plants of commercial size using this system have been erected in Europe; the first at Oldenburg, Germany; the second at Redkino, Russia, by the Russian Government in 1901, and the third at Beuerberg, Bavaria, in 1904. The last-named plant embodies many improvements, and at the time of its construction was the most complete establishment for making coke and by-products from peat that had then been developed. Each of these plants is built on the unit system, each unit consisting of two vertical retorts about 40 feet high and elliptical in cross section. The lower half of each retort is of fire brick and the upper half of cast iron, covered with thin fire bricks, and the two halves are inclosed in a fire-brick shell. Between the two shells are horizontal fire flues. The whole structure is inclosed by a covering of common brick to prevent loss of heat through radia-

tion. The retorts rest on a cast-iron base and taper down to hoppers, each with two openings, closed by air-tight doors, through which the peat coke can be removed as often as desired. In practice the coke is drawn off once an hour into iron cars with air-tight covers and is kept in the cars till cool. The tops of the retorts have heavy cast-iron doors, to which are attached feed boxes with gas-tight covers, opening inward. By this provision new fuel can be introduced whenever necessary without interfering with the operation of the retorts, so that coking is continuous. The volatile matter is drawn off through pipes in the upper half of the retorts by suction fans and led to condensing chambers; there it gives up a part of its heat to concentrate solutions and dry some of the by-products, the tar and tar water being removed by condensation. The uncondensed gases are returned to the combustion chambers to serve as fuel.

The hot gases from the fires, having a temperature of more than 1,800° F. (1,000° C.), are drawn through the fire-brick flues in the walls inclosing the retorts, and thence to a main flue connected both with drying chambers, in which the drying of the peat bricks is completed, and with the chimney.

As indicated above, the heat of the gases leaving the retorts is used to concentrate and dry out part of the by-products by being drawn under the vessels containing them. The by-products plant is in a separate building, and as the essentials of the processes used in it are described on pages 131–132, details regarding it are unnecessary at this point.

Besides the retorts in which the peat is thoroughly coked at the Beuerberg plant, each pair of these is directly connected with a circular retort for making half coke or "semicoke," from low grades of peat by using the heat of the waste combustion gases from the coking retorts. These gases, because they have no free oxygen, and hence can not set fire to the peat, are conducted from the collecting flue of the coking retorts directly into the halfcoke ovens, and are hot enough to thoroughly carbonize the peat without driving off all of the tarry compounds. The resulting product is not as hard and firm as the peat coke, and is lower in carbon and richer in hydrogen, but it makes excellent fuel for heating, as it burns with a long bright flame.[a] The Ziegler plant at Redkino, Russia, is reported to have manufactured this product for fuel for locomotives on the railways of the country, and 1 pound of it is said to have evaporated 6.63 pounds of water in a stationary boiler and 5.76 pounds in a locomotive boiler.[b]

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[a] Nystrom, E., Peat and lignite; their manufacture and uses in Europe. Can. Dept. Mines, Mines Branch, 1908, pp. 181–183.

[b] After running for some months with seeming success, the Beuerberg plant was closed, and has not been operated since. Among the reasons given for the failure of the plant was the great difficulty, except at prohibitive cost, of drying the large quantity of machine peat bricks before they were placed in the retorts.

A good quality of coke can be made from dense, thoroughly decomposed peat that has been machined and air dried, but the coke must be manufactured under favorable conditions of market and on a large scale, and, if the best financial returns are expected, the coking must be accompanied by the recovery and profitable sale of the chemical by-products and the utilization of the noncondensible gases as fuel for heating the retorts and for drying the peat preliminary to coking.

By such treatment there can be obtained from peat the following useful substances:

(1) Coke, or charcoal, the nonvolatile part of the peat, consisting of the fixed carbon and the ash or incombustible mineral solids.

(2) Tar, a mixture of the more readily condensed hydrocarbon compounds formed by the destruction of the complex organic substances in the peat.

(3) Tar water, or, as it is sometimes called, gas water, a solution of a number of the lighter, less easily condensed organic compounds in the water originally present in the peat or formed by the decomposition of original hydrogen compounds.

(4) Fixed gases, a considerable part of the volatile matter given off by peat heated in a retort, which before purification form a mixture of elementary and compound gases, some of which are combustible. The yield of gas varies considerably for different kinds of peat, the less decomposed giving the largest quantity and poorest quality.

Coke made from peat differs much in purity and hardness, depending on the kind of peat, the thoroughness with which the peat is macerated before coking, and the extent to which the volatile matters are driven off. The best peat coke is black and has the luster of jet, or it may be even of graphite color; it is hard and compact, but retains the original structure of the macerated peat. Such peat coke is quite as strong as good, hardwood charcoal, and may even surpass the latter in resistance to crushing. ,

The percentages of sulphur and phosphorus are usually very low, and if the peat was good the ash content is also low. Burned under the proper conditions the coke gives practically the same temperature as good charcoal, about 4,300° F. (2,380° C.); it has practically the same calorific power (12,000 to 14,000 B. t. u. per pound). Peat coke has been used in making gunpowder, in purifying water and solutions containing organic matter, in smelting and refining metals, in the manufacture and hardening of steel, and, to some extent, in making calcium carbide. Obviously, if it can stand the pressure of tall blast furnaces, it may replace charcoal in the manufacture

of charcoal iron, and the statement is made that retort-made peat coke is already replacing charcoal for this use to some extent in northern Europe. It may also be used wherever an efficient, smokeless fuel is desired, or in industries where such fuel is necessary.

The poorer grades of peat and those higher in ash are sometimes made into "half coke," a charcoal-like product in which some of the volatile matter is left. This has about 65 per cent of pure carbon, compared with more than 90 per cent in the thoroughly coked material. The amount of coke that can be obtained from a given weight of peat depends upon the thoroughness of the coking and the intensity of the heat. About 33 per cent of good coke is obtained by the Ziegler process of coking in retorts, and as high as 45 or 50 per cent of salable half coke may be had.

PROPERTIES AND DERIVATIVES OF TAR.

The quantity of tar that may be recovered from the distillation of peat in coking retorts is somewhat variable, but rarely exceeds 4 or 4.5 per cent of the dry weight of the peat used, and may run as low as 1.5 or 2 per cent.

Peat tar is a black, viscid liquid having a strong, smoky odor, often acrid and disagreeable. It may be used in the crude state as a wood preservative, or may be converted into a variety of commercially valuable substances by redistillation at various temperatures. The most important products of such treatment are light oil, heavy oil, wax, creosote, and asphalt.

METHODS OF RECOVERING TAR AND OF PURIFYING TAR DERIVATIVES.

In the Ziegler process the tar is condensed in a receiver which may be placed in the ground near the retorts. The tar is separated from the water condensed with it by heating the mixture in large open vessels to the melting point of the tar by the use of steam heat. The tar collects in a layer on top of the water, and after cooling may be removed to another tank, where the operation is repeated. The last traces of any ammonia still left in the tar are washed out with dilute sulphuric acid.

After the tar has been sufficiently freed from tar water and ammonia it is placed in a large cast-iron retort and melted with a small amount of a dilute solution of sodium hydroxide. It is then distilled slowly until all of the water and some of the light oils have been liberated. After the water ceases to pass off from the retort, the distillate is collected in a second receiver and heating continued until about 10 per cent of the amount of the tar has passed over. The product is then removed, the heat is increased, and the distillation allowed to proceed until crude, heavy oil, mixed with paraffin wax, has collected in the receiver to an amount equal, approximately, to 33 per cent of the tar taken. The hot tar residue is then dipped from

the retort and molded into blocks of asphaltum, and the crude mixture of paraffin and heavy oils is placed in tanks having valves at various heights on the sides. The mixture is stored in cold underground storerooms until the wax separates from the oil and becomes solid. The valves in the containers are then opened, one at a time, beginning at the top, and the oil pressed out from the openings and added to the crude oil already collected. The final residue of heavy oil which serves as lubricating oil is removed from the wax by pressing it cold. The wax is allowed to accumulate until enough is on hand to pay for its purification, after which it is melted, filtered through felt, and after some further purification molded into candles or other salable form.

The crude oils, which are said to be identical with petroleum in properties and appearance, are refined by adding enough caustic soda to separate the creosote and similar compounds from the oil. The soda is added to the oil in definite proportions, depending on the amount of creosote found by analysis, and the mixture of oil and reagent is agitated for an hour or more to insure complete union of the creosote and soda. The tank in which this reaction is carried on has valves at intervals down the sides. After the stirring is completed the mixture is allowed to stand for several hours until the oil and creosote solution separate.

After the separation is completed the oils are drawn off into a lead-lined vat, 5 parts of concentrated acid for each 100 parts of oil are added, and the mixture is stirred for about an hour to remove certain organic impurities. The oil that separates from the acid is drawn off from the top, again treated with caustic soda, and then distilled in an iron or copper retort. The first oil obtained is usually yellowish, and this portion is saved separately. The colorless distillate is run into barrels; when the specific gravity of the distillate reaches 0.83, the receiver is again changed and the heavy oils that have an average specific gravity of 0.85 are collected. The residue left in the retort at the end of the distillation consists of tar and sodium hydroxide, or, if the heating be carried far enough and all the volatile matter be driven off, only carbon in the form of graphite remains. This can be converted into carbons for electric lights.

Creosote and resin compounds may be obtained from the soda residue collected during the purification of the oils by placing the residue in a proper vessel and adding sulphuric acid until no more oil separates. This oil forms a distinct layer above the acid, and may be drawn off into another vessel, where it is washed with water. A strong solution of caustic soda is added in the proportion of 1 part of solution to 10 parts of oil, until about 70 per cent of the oil has boiled over. The residue left in the retort is crude sodium resinate, which may be used in making lampblack or gas carbon. If the crude creosote

resulting from this treatment is to be further purified, the processes described must be repeated several times. As such purification pays only when conducted on a large scale, the crude creosote obtained from small plants can best be utilized by treating it with finely powdered and sifted slaked lime. The product is a crude calcium creosote compound that can be sold for disinfecting purposes.

The tars obtained at the Beuerberg coking plant in Bavaria (Ziegler process) are said to have been converted into a soaplike product which makes excellent axle grease by adding lime and resin oil to the tar. This disposition of the tarry material is simpler and requires much less apparatus than the process described above, and if the product can be sold in sufficient quantities makes the disposal of the tar a relatively easy matter.

DERIVATIVES FROM TAR WATER.

The character of the derivatives from tar water depends to some extent on the kind of peat; the less decomposed, fibrous kinds yield more methyl alcohol and acetic acid and less ammonia than the darker colored, thoroughly decomposed, and structureless kinds, which contain more combined nitrogen. The tar water from the condensers is practically a dilute watery solution of ammonia salts, acetic and other organic acids, and wood alcohol, together with smaller quantities of finely divided tarry matter.

In recovering these substances on a commercial scale several methods are in use. By one of them the tar is removed by filtering through a charcoal filter, the clear filtrate is made alkaline with calcium hydrate, and filtered again through a fine cloth. This separates the bases (from which aniline and other organic compounds may be obtained) from the filtrate, containing the acetic acid compounds, ammonia, and methyl alcohol.

This filtrate is then placed in a retort and the ammonia and methyl alcohol, together with much of the water, are distilled over into a receiver. As the distillation proceeds the heat causes certain tarry substances to separate from the residue in the retort, and these have to be removed as fast as formed, so that they will not decompose and discolor the solutions on further heating. The latter part of the distillation, after the residue, which is principally calcium acetate, becomes concentrated, is carried on at low temperature, and is accompanied by constant stirring of the solution, so as to prevent any decomposition of the acetate.

The liquid containing the ammonia and methyl alcohol is neutralized with sulphuric acid, filtered to remove impurities, and again distilled to obtain the methyl alcohol, which is further purified and concentrated by redistillation and by passing the distillate over layers of quicklime to remove the water. After the methyl alcohol

has all been driven off, the residue, which contains the ammonia in the form of ammonium sulphate, is filtered again and slowly evaporated in an open iron vessel until the salt begins to crystallize. The temperature is then decreased and the liquid stirred vigorously until the ammonium sulphate is thoroughly dry.

The recovery of these three compounds (ammonia, wood alcohol, and acetic acid) may be accomplished on a very large scale by modifications of the processes described, including the use of towers through which the gases from the coking retorts are passed, and in which they are brought in contact first with sulphuric acid to fix the ammonia and then with milk of lime to remove the acetic acid. The materials obtained are purified and concentrated as previously described. The most recent practice, however, eliminates the towers.

PERMANENT GASES FROM COKING RETORTS.

As with the other by-products discussed, the volume and composition of the uncondensible part of the distillates from peat-coking retorts vary with the kind of peat used, the amount of water present, and the temperatures at which the coking is carried on.

As the present discussion relates to the by-products recoverable from coking ovens, the figures furnished by the Ziegler peat-coking plants in operation in Germany are valuable and instructive. In a test run at the plant at Oldenburg, in which 576 tons of peat were used, the noncondensible gases were found to be 57.3 per cent of the whole product, and of this quantity about 20 per cent was air, leaving 37 per cent, or 213.4 tons, as the amount available for use.

The uncondensed gases before purification were found, according to official reports cited by Nystrom [a] to have the following composition:

Analysis of uncondensed gases from retorts at the plant at Oldenburg, Germany.

Gas.	Weight.	Volume.
	Per cent.	*Per cent.*
Carbon dioxide (CO₂)	48.8	27.4
Oxygen (O)	2.8	2.2
Nitrogen (N)	25.5	22.5
Carbon monoxide (CO)	9.7	8.6
Methane (CH₄)	9.6	14.8
Other hydrocarbons (C$_n$H$_m$)	1.7	1.0
Hydrogen (H)	1.9	23.6

This gas had a calorific value of 322 British thermal units per cubic foot.

a Nystrom, E., Peat and lignite; their manufacture and uses in Europe: Can. Dept. Mines, Mines Branch, 1907, p. 180.

A later report, from the Ziegler peat-coking plant at Beuerberg, gives the composition of the gases obtained there as follows:

Analysis of uncondensed gases from retorts at the plant at Beuerberg, Germany.

Gas.	Volume.
	Per cent.
Carbon dioxide (CO₂)..	15.5
Oxygen (O)...	1.1
Carbon monoxide (CO)..	20.4
Methane and other hydrocarbon gases (CH₄ and CₙHₘ).............................	12.4
Hydrogen (H)..	28.6
Nitrogen (N)..	21.9

This is a better fuel gas than the first one, as it contains a lower percentage of carbon dioxide and more carbon monoxide and hydrogen.

Properties.—Of the gases found by these analyses, carbon dioxide, oxygen, and nitrogen are not inflammable, although the oxygen aids in the combustion of the fuel gases present. Carbon monoxide and hydrogen give heat but nonluminous flames so that they are not available for illuminating purposes when pure, unless incandescent burners of the Welsbach type are used. The methane and other hydrocarbon gases given in the analyses, however, burn with a bright light, and may be termed illuminants. The illuminating power of the peat gas depends on the percentage of illuminants in the gas, and this, in turn, is largely governed by the intensity of the heat developed in the coking retorts and the degree to which the coking is carried.

Volume per unit of peat.—The volume of gas derived from coking peat is quite variable, but in experimental work 100 pounds of dry peat are reported by Ryan [a] to yield from 475 to 519 cubic feet of illuminating gas, when treated in a retort, whereas other writers report 300 to 430 cubic feet from the same weight of peat. The volume of gas obtained from ovens of the Ziegler pattern is reported to have been, in one test, 6,650 cubic feet of gas to the metric ton (2,204 pounds) of dry machine peat coked, or about 300 cubic feet from 100 pounds of peat.

Uses.—The noncondensible gases obtained in the ways described are, in part, combustible, and may be used for illuminating or for fuel. If they are to be used for lighting, they must be purified by removing carbon dioxide and other impurities or diluents, and, as a rule, enriched by the addition of some of the hydrocarbon compounds obtained by heating the tars in retorts. The peat gas may be used as a source of power by burning it under steam boilers or

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[a] Ryan, Hugh, Reports upon the Irish peat industries, pt. 2: Econ. Proc. Roy. Soc. Dublin, vol. 1, pt. 13, pp. 519, 520.

in the cylinders of internal-combustion engines. It may be used for heating the coking retorts, for generating the heat or power needed for handling and drying the peat, and for any other purpose in the process of making peat coke and recovering by-products. The actual value of this gas for the uses given is estimated by Dr. Ziegler to be fully 25 per cent of the value of the coke obtained, and with it and the waste heat from the retorts he carried on all of the operations about his plants, after the coking operation was once started, including the manufacture of peat charcoal or "half coke" from the poorer grades of peat.

QUANTITY OF BY-PRODUCTS OBTAINED FROM COKING PEAT.

Thenius, as cited by Ryan [a] obtained from good air-dried peat the following by-products:

Percentage and weight of by-products per ton of air-dried peat.

Substances.	Percent-age.	Pounds per ton.	Substances.	Percent-age.	Pounds per ton.
Charcoal	35.34	706.8	Asphalt	1.56	31.2
Tar water	40.00	800.0	Creosote	1.08	21.6
Light petroleum	1.76	35.2	Gas and loss	15.63	312.6
Heavy petroleum	2.56	51.2			
Lubricating oil	1.77	35.4		100.00	2,000.0
Paraffin wax	.30	6.0			

From 100 pounds of dry peat tar the same investigator reports the following as obtained by distillation:

Products of distillation from 100 pounds of dry peat tar.

Substances.	Crude.	Purified.	Substances.	Crude.	Purified.
Light petroleum (density less than 0.83)	Pounds. 16	Pounds. 12	Paraffin wax	12	2
			Asphalt	16	16
Heavy petroleum (density 0.85)	30	25	Creosote		0
Lubricating oil	15	15	Gas and loss	11	23

From 100 pounds of tar water there was also obtained:

Pounds.
Ammonium sulphate 4.0
Methyl alcohol 2.0
Pyridine bases 2

These figures, when reduced to pounds of the substances per short ton of peat (800 pounds of tar water can be obtained from a ton of peat), became:

Pounds.
Ammonium sulphate 32.0
Methyl alcohol 16.0
Pyridine bases 1.6

In addition, acetic acid can be recovered in the form of calcium or potassium acetate, equivalent to 12.6 pounds of the pure acid to a ton of dry peat.

The processes for the recovery of these compounds from the tar and the tar water have already been described, and although the necessary equipment is simple, the operations require high-priced supervision and skilled labor, as well as much heat from some cheap and convenient source. On account of the cost of these items and of maintaining the plant, very large quantities of crude materials must be treated to make profitable the recovery for commercial purposes of any or all of the substances mentioned as by-products.

Dr. Ziegler estimates that in actual practice in a well-equipped Ziegler plant, capable of coking 100 tons of air-dried machine peat each day of 24 hours, the total quantity and value of by-products will be as follows: [a]

Quantity and value of by-products from 100 tons of air-dried machine peat each day of 24 hours.

Product.	Quantity.	Selling price per unit.	Value.
Ammonium sulphate...........................pounds..	900	$3.07 per 100 pounds...	$27.63
Acetate of lime..............................do....	1,320	2.35 per 100 pounds...	31.02
Methyl alcohol..............................gallons..	65	.70 per gallon.......	45.50
Light oils.....................................do....	280	.07½ per gallon......	21.00
Heavy oils....................................do....	95	.07½ per gallon......	7.12
Paraffin.....................................pounds..	715	.03¾ per pound......	26.81
Creosote oil or carbolic acid..................do....	3,100	.02¼ per pound......	69.75
Asphalt.......................................do....	440	.00½ per pound......	2.20
			231.03
Deduct 10 per cent for the expenses of selling..............			23.10
Total......................................			207.93

This total value of the by-products may be subtracted from the cost of producing the peat coke, which, after the deduction has been made, is given as $1.74 to $3.05, depending on the cost of producing the machine peat and delivering it to the coking retorts. The cost of making the coke includes all proper charges for plant, labor, maintenance, etc. As the price received for the best quality of peat coke in Germany[b] is $13.20 (55 marks), or even more, per ton, and for the poorer grades $6 to $9 (27 to 36 marks) per ton, the margin of profit for the investment of capital is excellent in that country, especially with large plants operated for the recovery of by-products. Whether the opportunities are as good in the United States, where there is a great iron industry and an active demand for the chemical substances made as by-products of peat-coke manufacturing, can be shown only by the actual development of a plant.

[a] Nystrom, E., Peat and lignite; their manufacture and uses in Europe, Can. Dept. Mines, Mines Branch, 1908, p. 186.

[b] Nystrom, E., Peat and lignite; their manufacture and uses in Europe, Can. Dept. Mines, Mines Branch, 1908, p. 181.

Each additional process adds to the initial expense of a plant, and it is to be expected that any system of coking peat will involve a large preliminary investment for retorts and other equipment, as well as for buildings, which must be larger and more substantial than those for briquetting in order to accommodate the apparatus necessary for conducting operations on a profitable scale.

The estimated cost of a four-oven plant built according to the plans of the Ziegler system and capable of coking 35,000 tons of air-dried peat per year, or about 100 tons of peat per day of 24 hours, is given by Dr. O. K. Zwingenberger, of New York, formerly agent for the United States for the company controlling the Ziegler patents, as $160,000. Of this amount $100,000 is for building and equipping the plant and the remainder for necessary working capital. The figures are based on American prices for materials and labor.

As only about one-third of the weight of the peat charged into the ovens is recovered as coke, or less than one-half if the main product is "half coke," a small plant, handling but a few thousand tons of air-dried peat in a year, would manifestly be operated at a disadvantage. Such a plant could hardly prove profitable, even if the by-products were all recovered and sold on the best possible basis, because as many costly operations and high-priced men are needed in a small plant as in a large one.

MANUFACTURE OF PEAT COKE IN THE UNITED STATES.

That peat coke would find a ready market in this country in the regions where iron ores are mined seems probable, however, as it could be profitably used there to produce high-grade charcoal iron. The manufacture of such iron is now carried on in northern Michigan and the adjacent regions at a great cost for the hardwood lumber that is converted into charcoal, although in the same territory, and especially in Minnesota, there are extensive beds of peat that have never been used for any purpose. There should also be a good market for the product as fuel in large cities and in parts of the country where anthracite is high-priced or unobtainable.

A single small plant making peat charcoal for fuel was in operation at New Haven, Conn., for several years, but the output was small and the quality of the original peat was poor, so that the product had only a small local market. Other systems for making peat coke have been advertised as originating in the United States, but so far as can be learned only one of them has yet actually been embodied in a working plant. A plant for making peat coke has been reported in operation in southern California, but no account of it has been received and no report can be made as to its operations. In fact,

so far as is known at this writing, the Ziegler system is the only peat-coking system so far worked out in a full-sized plant that has operated successfully from a financial point of view, except that at Elizabethfehn, Germany, designed by Dr. W. Wielandt, of which no detailed description has been received.

Peat coke should be produced in the United States by a plant equipped for the recovery of by-products and handling 100 tons of air-dried machine peat per day, at a cost of from $3 to $3.50 per ton of coke, if the by-products are sold at current rates. Included in this estimate are fair charges for digging and air drying the peat, for machinery, and for all other charges that should be borne by the plant.

The price at which the coke can be sold will probably vary, according to the quality of the coke, the locality in which it is made, the purposes for which it is to be used, etc., but it should about equal that of charcoal, or $6 to $12 or more per ton. As the price of charcoal will continue to advance with the exhaustion of the available wood supply, there is a good prospect for an equivalent increase in the probable price of peat coke, because peat coke can be used not simply as a substitute for charcoal but, if of the best grade, as a superior article.

The experience gained by those who have attempted to make peat coke in Europe points clearly to the fact that the operation is not commercially successful unless the peat is of the best quality and the coking is conducted in such a way as to utilize the heat of the gases from the retorts for various purposes throughout the plant. If the coking is to be profitable the condensible distillates should be saved and made into a series of salable chemical by-products.

The amount of capital needed for developing a proper plant for making peat coke is so large that the investment is scarcely justified unless a preliminary attempt is made not only to find a market for the coke, but to learn where, in what quantities, and at what prices the by-products can be sold and, if possible, to have at least a part of the output sold conditionally.

MANUFACTURE OF GAS FROM PEAT.

HISTORY.

A few years ago it was predicted that with the rapid introduction of improvements in lighting by electricity the use of gas for illuminating purposes would decrease. Almost at the same time, however, came entirely new forms of gas burners, in which the light is derived from the incandescence of the oxides of certain rare metals, instead of from that of the carbon particles in the flame itself. In these burners the gas is completely burned and the oxides, in the form of a porous

mantle, are intensely heated.   Much less gas is used than with the old patterns of burners, and much more light is obtained.   In addition the cost of gas was decreased by improved methods of manufacture, so that the price of gaslight, for the candlepower obtainable, became much cheaper than ever before.

Accompanying the improvements by which gas could be furnished to the consumer at lower prices came also the invention and popularizing of correctly designed burners, stoves, and other apparatus for using gas as a domestic fuel and for the generation of steam power. The convenience, cleanliness, and efficiency of the fuel more than offset its somewhat greater cost for these uses as compared with wood or coal at the prices that those fuels bring in many localities.

In still another direction there has been a great advance in the use of gaseous fuel.   This advance has gone on so rapidly that only mechanical engineers especially interested in power development realize the rate at which the change is taking place.   This is the development of engines in which the energy of the fuel is converted into power by its ignition and sudden expansion in the cylinders of the engines.

Besides these important advances in the use of gas, improvements in generators and gas producers, and investigation of the properties of gases derived from many kinds of fuel have demonstrated that gas can be profitably made from fuels that have long been regarded as practically worthless.   With these improvements there have been modifications of the gas engine that make practicable the use of the poorest grades of producer gas.   In view of all these facts, the possibility of using peat for the manufacture of gas becomes an important topic for investigation in regions where coal is not found and peat is abundant.

It has already been shown that gas of good quality is obtained when peat is heated in retorts and that this gas can be used for fuel and, after purification and enrichment, for lighting.   Doubtless, also, it would without enrichment provide ample light if burned in incandescent types of burners.

ILLUMINATING GAS.

REQUIREMENTS FOR SUCCESSFUL PRODUCTION.

Excellent illuminating gas may be prepared from peat by distilling it in cast-iron retorts heated from the outside.   To secure satisfactory commercial results, however, the retorts for making a given quantity of gas must be larger for peat than for coal, and the outlet pipes must be of larger diameter because the peat gives off large quantities of gas quickly; the condensing apparatus also must be more efficient than that required for coal gas, because of the greater proportion of watery and tarry products.

The distillation of peat for illuminating-gas manufacture must be carried on at a red heat, or higher, in order to decompose the heavier

hydrocarbons into permanent gases that will furnish substances to brighten the flame when the gas is burned. To maintain this high temperature, the fire boxes of the retorts must be larger than for making gas from coal, and more fuel must be burned to continue the necessary decomposition of the tars.

If distillation is carried on at temperatures that are too low, the gas contains much carbon dioxide and gives a colorless flame when burned; the percentage of carbon dioxide may reach 25 to 30 per cent and even more if the peat used is not thoroughly dry when it is put into the retort. The evaporation of the water present lowers the temperature of the gases formed so much that the carbon dioxide developed is not decomposed.

COMPOSITION.

The composition of peat gas is reported to vary considerably, being dependent upon the temperature of distillation, the character of the peat, the quantity of water in the peat, and the method of distilling.

Ryan [a] gives the following tables as indicating the average composition of peat gas:

	Per cent.
Methane (CH_4)	30
Carbon dioxide (CO_2)	30
Hydrogen (H_2)	19
Carbon monoxide (CO)	14
Heavy hydrocarbons	7
Nitrogen (N_2)	Trace.

The gas after it has been purified by the removal of the carbon dioxide shows the following composition:

	Per cent.
Methane (CH_4)	42.5
Hydrogen (H_2)	27.5
Carbon monoxide (CO)	20.0
Heavy hydrocarbons	9.5
Carbon dioxide (CO_2)	.2
Nitrogen (N_2)	.3

The carbon dioxide is removed by slaked lime, and the necessity of using a large quantity of lime, compared with what is necessary for coal gas, has operated against the use of peat as a source of illuminating gas.

Peat gas may also contain sulphur compounds and considerable ammonia, the proportion of the former depends upon the proportion of sulphur in the peat, and of the latter upon the percentage of combined nitrogen in the peat and the temperature at which distillation is carried on. The proportion of nitrogen that combines with hydrogen to form ammonia is much larger at low than at high temperatures.

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[a] Ryan, Hugh, Reports upon the Irish peat industries, Pt. II: Econ. Proc. Roy. Soc., Dublin, vol. 1, pt. 13, pp. 520–521.

The quantity of sulphur compounds in gas distilled from fresh-water peat will nearly always be considerably lower than in coal gas, because such peat contains less sulphur than coal; but peat that has been subjected to the action of salt water is likely to have a relatively high percentage of sulphur, and this will appear in the gas derived from it.

QUANTITY OF GAS PER UNIT OF PEAT.

The yield of gas from a pound of peat in a given time is reported to be greater than that obtainable from a pound of coal in the same time, so that fewer retorts are needed for a stated production of gas. The volume of gas obtainable from good, properly dried peat by the use of well-designed and well-constructed retorts and of temperatures high enough to decompose the tars, is almost equal to that yielded by English cannel coals under equally good conditions, the peat giving from 8,900 to 10,400 cubic feet per ton of 2,000 pounds, and Newcastle coal giving about 11,400 cubic feet per ton.

Peat gas is heavier and denser than coal gas, hence it must be burned under greater pressure if coal-gas burners are used for it, or if burned without pressure the openings in the burners must be made larger to get as good results.

CAUSES OF FAILURE IN PAST EXPERIMENTS.

It is apparent from the facts recited that experimental runs with peat as a source of gas in retorts made for generating gas from coal, and by men familiar only with the manufacture of coal gas, would yield results of negative value and a very unsatisfactory product. The history of the attempted commercial use of peat for the production of illuminating gas on a large scale is principally a record of such attempts and of failures resulting from them. They have been carried on in Europe principally, but on a small scale attempts were made to use peat for illuminating-gas production in parts of New England, New York, and New Jersey about fifty years ago. The results were reported satisfactory, although, as the use of peat for the purpose was not continued, it seems probable that there was a technical failure, due, in part at least, to a lack of appreciation of the underlying principles as outlined above. From 1894 to 1896 peat gas was made at the works of the Cambridge Gaslight Company, Cambridge, Mass., under patents of W. F. Brown, but the process was finally abandoned on account of the cost and poor quality of the cut peat used.

PRESENT STATUS OF GAS MANUFACTURE.

The use of coal is so much more general now than when the experiments were made of which definite reports have given, that it would

be difficult to secure their repetition. No localities where peat is now used as a source of illuminating gas in Europe are reported in the latest advices from the countries where such use has been attempted, so that it may be safely assumed that, in spite of the practicability of making illuminating gas from peat, it is not now used for the purpose on a commercial scale; that it might be so used in properly designed and constructed plants in regions remote from supplies of suitable coal and where peat is common is clearly indicated.

WATER GAS.

In recent years a type of gas known as water gas and enriched or carbureted water gas has been used extensively for illuminating purposes. This gas is obtained by bringing steam into contact with incandescent carbon in the form of coke. The steam is decomposed and its oxygen unites with the carbon to form carbon monoxide, leaving the hydrogen free. The mixture of carbon monoxide and hydrogen burns with an intensely hot but slightly luminous flame. To give this gas, which is nearly identical with the gas from some forms of gas producers, illuminating elements, the heavier hydro-carbons are added to it. A common method of enriching water gas is by injecting naphtha or gasoline into it. The enriched gas gives a bright flame of good candlepower. It is the type of illuminating gas supplied in many cities of the United States, as it can be made at much less cost than that obtained by the destructive distillation of coal. Peat, although used to make producer gas, does not seem to have been tested for making the carbureted water gas, but such use is evidently possible.

FUEL GAS.

Gas is now much used as a source of heat for power and other purposes, and is rapidly growing in favor for such uses, because of its high efficiency, cleanliness, and the ease and cheapness with which it is handled.

It is apparent from what has already been said regarding the quality and quantity of gas to be had as a by-product of peat distillation or of coking operations that the subject should prove attractive to the engineer seeking a cheap and unutilized fuel as a source of power and fuel gas. Moreover, it is known, from the unqualified statements of trustworthy, unprejudiced, and competent observers, that peat is being given a thorough trial for power-gas production in several European countries where there is an increasing need for fuel for manufacturing industries. In Sweden and Germany this use has passed to the commercial stage of development.

PRODUCER GAS.

The generation of gas for burning under boilers and for direct use in gas engines places few of the limitations on the process or the gas that are inherent in the manufacture of gas for lighting. The main object is to get as much as possible of the heat energy from the original fuel in the form of inflammable gas, yield and uniform composition being more important than the thermal value to the unit of volume or the proportion of inert gas present. For these reasons the use of retorts has been abandoned as too costly for manufacturing gas for fuel and power purposes. In their place have been substituted gas producers in which the fuel elements of the combustibles, the carbon, both fixed and volatile, and the hydrogen are all used, the entire body of fuel being converted into permanent gas and ashes. The process of making gas in a gas producer differs from that of making illuminating gas in that a part of the fuel is burned inside of the producer to furnish the heat necessary for gasification and in that no fixed carbon or coke remains.

Used in this way there is a loss of fuel to the extent that heat units are required to bring about the chemical changes necessary to reduce the solid compounds of the fuel to permanent gases that have the power of combining with the oxygen of the air and thus developing heat. In the gasification of fuel in retorts the loss of heat units is even greater than in the gas producer.

The gas producer differs from a common furnace in that less oxygen is admitted to the combustion chamber and the fuel bed is thicker. In an ordinary furnace the effort is made to have the fuel elements take up all of the oxygen possible, and air is furnished in excess of the supply needed for complete combustion in order that the energy of the fuel may be converted rapidly into heat. In the gas producer only sufficient oxygen is supplied to completely satisfy enough of the carbon and hydrogen units of the fuel to convert the rest of it into permanent gases; in other words, in the gas producer the combustion of the greater part of the fuel is incomplete.

Producer gas, therefore, is obtained by gradually converting solid fuel to the gaseous state by the heat given off from the complete combustion of a part of the fuel. The character and composition of the resulting gas is quite variable, according to the kind of fuel and the type of gas producer used.

DESCRIPTION OF GAS PRODUCER.

The simplest form of gas producer for power-gas generation is a vertical cylinder of iron or masonry, lined with fire brick, having a grate near the bottom, an opening in the top for charging fuel, a smaller opening near the top for the outlet of the gas, and one near the bottom for the admission of air. Openings are also provided at

various heights on the sides, through which the interior may be reached for poking the fuel bed, inspecting and cleaning the interior, making repairs, and removing ashes. To prevent the entrance of air except through the proper openings, which are covered by gas-tight doors, the bottom of the producer is placed in a shallow tank of water, into which the ashes and refuse fall, and the charging opening is generally a small chamber, guarded by gas-tight doors at the bottom and top, which prevents the escape of the gas and the ingress of air while the producer is being recharged.

SCRUBBERS AND REGENERATORS.

Simple gas producers such as described above furnish uncleansed gas, which contains so much dust and other foreign matter that it is unsatisfactory for use, especially in gas engines. Power-gas producers are therefore provided with apparatus for cleansing the gas, known as scrubbers, through which the gas passes after leaving the producer. The scrubber in its simplest form is a cylindrical chamber filled with some porous material like coke or shavings, which is kept constantly wet. The gas, in passing through this wet material, leaves behind most of the solid and liquid impurities it contains.

In addition to the scrubber, many gas producers have attachments for preheating the air admitted for combustion, so that it enters the fire at a temperature sufficiently high to prevent cooling of the fuel. Such attachments make use of the heat of the off-going gases, and are called regenerators.

THEORY OF GAS FORMATION IN A GAS PRODUCER.[a]

When such a gas producer as that described is in operation, there is at the bottom an inert layer of ashes to protect the grate. Above this layer is the part of the fuel bed where combustion is complete and the temperature highest. Still higher in the thick fuel bed is a zone of incandescent carbon or coke from which the volatile matter has already been driven; at the top is the layer of fuel most recently added, from which the heavier gases and volatile matters are being driven, or distilled, by the heat from below.

Clearly, the gas from the layer of complete combustion must pass up through the layers above it; if the combustion is properly regulated, all of the carbon of the fuel in the lowest layers will be converted into carbon dioxide as expressed by the chemical equation

$$C_2 + 2O_2 = 2CO_2.$$
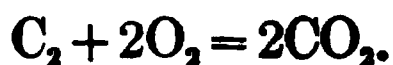
The nitrogen of the air used is inert, and hence is not taken into account in the equation. The carbon dioxide, on reaching the layer of

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[a] For a more complete discussion of the theory of the formation of gas in gas producers, see Bull. 7, Bureau of Mines. 1911. 58 pp.

incandescent coke, gives up a part of its oxygen to the hot carbon, converting each carbon molecule thus attacked into two molecules of carbon monoxide; at the same time two molecules of the carbon dioxide are reduced to carbon monoxide, according to the chemical equation

$$2CO_2 + C_2 = 4CO.$$
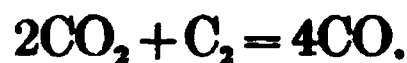
As all of the combustibles in the fuel at the bottom of the producer are united with oxygen, only the ash remains, and the residue of coke from the incandescent layer settles down or is poked down to be completely gasified.

If the fuel used in this way were charcoal or coke—that is, pure carbon and ash—the producer gas would be a mixture of carbon monoxide and nitrogen, the simplest form of producer gas obtainable. The high price of the purer carbonaceous fuels has led to the use of other fuels to furnish the carbon, and to the use of steam, an oxygen and hydrogen compound, to supply part of the oxygen needed in the gas producer. The gas resulting from the decomposition of the steam by the incandescent carbon is a mixture of carbon monoxide, hydrogen, and nitrogen, as shown by the following equation:

$$C_2 + H_2O + CO_2 + xN = 3CO + H_2 + xN.$$

The nitrogen is merely a diluent, and the quantity in the gas depends upon the quantity of air used in proportion to that of steam.

The decomposition of the steam, however, requires much heat, and if too much steam is used the temperature is soon lowered below that at which the decomposition will go on. It is therefore necessary to keep the quantity of steam introduced small in proportion to the quantity of air used, or to turn the steam intermittently into the producer. It is evident that the gas thus generated is identical with water gas, except for the nitrogen present.

TYPES OF GAS PRODUCERS.

The form of producer in most general use for generating gas for the development of power, especially in gas engines, is that supplying gas directly to the engine, which draws the air and steam through the fuel bed by means of the suction stroke of the piston. The suction producer, as it is termed, has been largely restricted to the use of anthracite, coke, charcoal, and other fuels containing a low percentage of tarry compounds. When bituminous fuels are used these tarry compounds are likely to be carried over with the fixed gases into the engine and, condensing there, clog the valves, pipes, and other working parts, despite scrubbing apparatus. Recent improvements in methods of scrubbing, however, have so modified

the older practice as to make the use of fuels rich in volatiles comparatively free from such accidents, and their use in the suction type of producer is increasing.

The pressure gas producer is so designed that the air and steam necessary to develop the gas are forced into the fuel bed under enough pressure to drive the gases generated through the fuel bed and scrubbing apparatus into a gas holder. The gas is thus generated independently of the piston stroke of the engine, and may be thoroughly cleansed of tars and ash before it is used. For this reason the pressure type of gas producer is well fitted for using bituminous coal, lignite, and peat. This type of producer was first used in this country to generate gas for fuel in connection with metallurgical operations, and later was adapted to the needs of large power plants, anthracite being until recently the fuel chiefly used. The down-draft or inverted-draft gas producer, in which the heavier products of distillation are all decomposed and changed into simple permanent gases, constitutes a third type and seems to be the one most successfully used in Europe for peat gasification. In power-gas producers of this type the heated gases, rich in vaporized hydrocarbons, tars, and heavy gases, are drawn by exhaust fans from the top of the producer, where they accumulate above the freshly added fuel, down through the fuel bed. In the fuel bed, by contact with the heated carbon, they are converted into carbon monoxide and hydrogen, which, after cleansing, can be either stored in receivers or used in engines.

The use of air-dried peat in the down-draft gas producer brought out the fact that the variable water content of the fuel made difficult the keeping of the fire in the proper place at the top of the fuel bed. This trouble has been obviated by the construction of the double-zone gas producer, in which fires are maintained at both the top and the bottom of the fuel bed, and the air blast is turned in at the top or the bottom as conditions require. The gas outlet is in the side of the generator, the gas produced being withdrawn from between the two combustion zones.

USE OF PEAT IN GAS PRODUCERS IN EUROPE.

The commercial use of peat in gas producers as a source of both fuel and power gas seems to be successful in Germany and Sweden, fuel gas made from peat having for many years been in use in metallurgical operations, in brick and glass making, and in lime burning.

Gas producers for making power gas from peat are now advertised by several manufacturers of gas engines in Europe, and, as has been previously noted, there seems to be no reasonable doubt that such producers are in successful commercial operation in the countries

mentioned. New plants for utilizing this fuel are annually added to those already at work, and in 1910 it was reported that large electric power plants using peat for fuel in gas producers were running in Sweden, Germany, Italy, and England.[a]

PRODUCER GAS COMPARED WITH OTHER COMMERCIAL GASES.

Producer gas, as shown by the following table, is poor in the compounds giving illumination and comparatively rich in the inert gases, carbon dioxide and nitrogen. The presence of these diluents seems unavoidable, and reduces materially the number of heat units per cubic foot of the mixed gases.

Composition and heating value of commercial gases.

Character of gas.	H_2.	CH_4.	C_2H_4.	N_2.	CO.	O_2.	CO_2.	B.t.u. per cu. foot.	Authority.
Natural gas(Pittsburgh)	3.0	92.0	3.0	2.0				978.0	Wyer, S. S., Treatise on producer gas and gas producers, p. 50.
Oil gas	32.0	48.0	16.5	3.0		.5		846.0	
Coal illuminating gas	46.0	40.0	5.0	2.0	6.0	.5	.5	646.0	
Coke-oven gas	50.0	36.0	4.0	2.0	6.0	.5	1.5	603.0	
Carbureted water gas	40.0	25.0	8.5	4.0	19.0	.5	3.0	575.0	
Water gas	48.0	2.0		5.5	38.0	.5	6.0	295.0	
Producer gas from— Anthracite coal	20.0			49.5	25.0	.5	5.0	144.0	U. S. G. S. Bull. 332, p. 289.
Coke	11.1	.2	.1	57.5	21.9		9.2	120.6	
Bituminous coal	15.6	1.9	.4	52.0	20.9	.0	9.2	156.1	U. S. G. S. Bull. 332, p. 452, average 24-day endurance test.
Do	15.0	2.2	.5	53.2	19.2		9.9	151.0	U. S. G. S. Bull. 332, p. 28, average 47 tests.
Lignite	15.4	2.6	.4	51.8	18.8	.2	10.8	154.8	U. S. G. S. Bull. 332, p. 28, average 7 tests.
Florida peat	18.5	2.2	.4	45.5	21.0		12.4	175.2	U. S. G. S. Bull. 322, p. 28, 1 test.
Massachusetts peat	13.9	2.1		51.0	22.5		10.5	166.1	U. S. G. S. Bull. 290, p. 133, 1 test.
North Carolina peat	10.19	.4	.06	60.8	16.9	.4	10.9	109.7	1 test down-draft producer, U. S. G. S., Pittsburgh plant.
Swedish peat	8.5	4.4	.5	53.7	26.0		6.9		Kerr, W. A., Peat and its products.
Do	6.3	5.6	.9	57.6	10.0	.5	9.7	132.0	Nystrom, E., Peat and lignite, p. 222, average 10 tests.
Blast-furnace gas	1.0			60.0	27.5		11.5	91.0	Wyer, S. S., Treatise on producer gas and gas producers.

The value of these gases, when their energy is converted into power by means of properly designed and constructed gas engines, is not decreased in direct proportion to the decrease in the number of heat units, as would seem to be the case on inspection. Indeed, it was proven some years ago by the researches of Lencaushez and others that when used in correctly designed engines a very poor gas was nearly as efficient as a much richer one, the chief difference being that larger engines were required to develop the same horsepower with poor gas than with rich gas. Thus it is stated[b] that

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[a] See also Bull. 4, Bureau of Mines. 1910. 27 pp.

[b] Kerr, W. A., Peat and its products, 1905, p. 74.

a certain engine using ordinary coal or illuminating gas developed 80 horsepower, and with blast-furnace gas 67 horsepower, a difference of 16 per cent only, whereas the calorific values of the gases were about 600 British thermal units and 120 British thermal units, respectively, to the cubic foot, or a ratio of 5 to 1. Wyer [a] also points out the same fact, on the authority of one of the large manufacturers of gas engines. He states that "an engine that will develop 100 horsepower with natural gas will give only about 80 horsepower with producer gas, a loss of 20 per cent. With a 200-horsepower engine this loss will be about 15 per cent, and with sizes above 300 horsepower it would be about 10 per cent." He does not point out, however, that the calorific value of natural gas is 978 British thermal units per cubic foot and of producer gas from anthracite coal only 144 British thermal units per cubic foot, according to figures cited by him, or about one-seventh as great. Thus the loss in power is not at all commensurate with the relative heating values of the two kinds of gas, the poor gas being much more efficient than the rich one, even in an engine designed for using the better gas.

The principle brought out by these statements has been found to be of such general application that gas engineers confidently predict that the power gas of the near future will be producer gas having a heat value of about 100 British thermal units per cubic foot. The development of the power necessary for operating the great steel-making and manufacturing plant at Gary, Ind., by means of gas engines using blast-furnace gas entirely, shows how certain is the trend in the direction of the use of gases of low thermal efficiency.

Producer gas was generated from many kinds of low-grade and refuse coals at the fuel-testing plants of the United States Geological Survey at St. Louis, Norfolk, and Pittsburgh, and in the reports [b] of the operations of these plants will be found full accounts of the work done and the impressive and valuable results obtained.

VOLUME OF PRODUCER GAS OBTAINED FROM PEAT.

The quantity of producer gas to be obtained from peat is large, and depends, as has been stated, on the quality of the peat and the form of the producer. Thus, Kerr,[c] quoting from R. Aakermann, states that in Sweden the quantity of gas generated from 100 kilograms (220.4 pounds) of peat was 252 cubic meters (8,900 cubic feet), or about 80,000 cubic feet per ton of 2,000 pounds. The composition of this gas is given in the preceding table. Nystrom,[d] on the other

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[a] Wyer, S. S., Producer gas and gas producers, 2d ed., 1907, p. 229.

[b] U. S. Geol. Survey Bulls. Nos. 290 and 332; Prof. Paper No. 48. See also Bulls. Nos. 7, 9, and 13, Bureau of Mines.

[c] Kerr, W. A., Peat and its products, p. 84.

[d] Nystrom, E., Peat and lignite; their manufacture and use in Europe: Canada Department of Mines Mines Branch, 1908, p. 227.

hand, states that 48,000 cubic feet of gas were obtained per ton of water-free peat substance, the gas having a calorific value of 152 British thermal units per cubic foot. Ryan[a] reports that 100 cubic yards of gas, with a calorific value of 150 British thermal units per cubic foot, were yielded by 100 pounds of peat containing 26 per cent of water, or 54,000 cubic feet per short ton, in a Koerting suction gas producer, and that a Ziegler pressure gas producer is capable of affording 180 cubic yards of producer gas, having a calorific value of 135 British thermal units per cubic foot, from 100 pounds of average peat, or 97,200 cubic feet per ton. These figures are incorporated in the following table for purposes of reference:

Yield and calorific value of producer gas per ton of peat.

Make and type of gas producer.	Source of peat.	Yield of producer gas per short ton of peat.	Calorific value per cubic foot of gas.	Percentage of water in peat used.	Authority.
		Cubic feet.	*B. t. u.*		
Mond...................	Italy..............	48,000	152.0	Water free....	Nystrom.
Koerting suction........	Germany..........	54,000	150.0	26 per cent....	Ryan.
Do...................	Sweden...........	80,000			Kerr.
Mond...................	England..........	80,000	145.0	Water free....	Nystrom.
Ziegler pressure.........	Germany..........	97,200	135.0		Ryan.
Loomis - Pettibone down-draft.	North Carolina....	72,400	109.7	Water free....	U. S. Geol. Survey.
Taylor pressure No. 7...	Florida............	76,600	175.2	.....do.........	Do.

CALORIFIC VALUE OF PRODUCER GAS.

The calorific value of producer gas derived from peat is approximately the same as that from coal. Nystrom[b] reports the following results of a number of carefully conducted tests made in different parts of Europe to find the calorific value per cubic foot of producer gas obtained from peat:

Calorific value of producer gas derived from European peat.

Make of gas producer.	Locality.	Calorific value per cubic foot of gas.	Remarks.
		B. t. u.	
Koerting....................	Skabersjo, Sweden....	132	Producer specially designed for peat.
Luther.....................	Nymphenburg, Germany.	114	Average of 10 analyses; producer built for using peat.
Mond......................	Stockton, England....	145	Producer built for using soft coal.
Do	Winnington, England.	152	Do.

In the United States, records of only a small number of experiments with peat in gas producers are available, and seemingly very few such tests have been made. The two experimental runs made in

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[a] Ryan, Hugh, Reports upon the Irish peat industries, Pt. II: Econ. Proc. Roy. Soc., Dublin, vol. 1, pt. 13, pp. 524–526.

[b] Op. cit.

1905 and 1906 at the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., are of importance and interest not only because they were probably the first trials in this country of peat in a gas producer, but because they were made in a large pressure producer built to use anthracite. Unfortunately, in one of these tests the quantity of peat available was too small for a full test run, so that the results obtained must be considered incomplete.

In the first of these tests air-dried machine peat from near Halifax, Mass., was used. The average calorific value of the gas was 166 British thermal units per cubic foot. In the second test, of fifty hours' duration, air-dried machine peat from near Orlando, Fla., was used. The average calorific value of the gas was 175 British thermal units per cubic foot.

A third test was made in a down-draft producer designed for bituminous fuels, at the fuel-testing plant of the United States Geological Survey at Pittsburgh, in January, 1909, with air-dried machine peat from North Carolina. The average calorific value of the gas was 109.7 British thermal units per cubic foot, about the average value of the gas obtained from coal in this type of producer.

In order to show that these values are not materially different from those of producer gas developed from bituminous coal in the same gas producer and under the same test conditions, the first two values may be compared with those obtained from tests with this fuel made at the St. Louis fuel-testing plant during the same year.

Thermal value of producer gas made from bituminous coal.

	B. t. u. per cubic foot.
Indiana (average)	147
Kentucky	164
Illinois	143
Ohio	157
Pennsylvania	142
Virginia	157
North Dakota lignite	161

The calorific value per cubic foot of standard gas obtained from fifty-six producer-gas tests with bituminous coal, made from January 1, 1906, to March 1, 1907, with the same gas producer, were:[a] Average, 151 British thermal units; maximum, 171.6 British thermal units; minimum, 122.5 British thermal units. From these results it is apparent that none of the coals gave as rich a producer gas as the Florida peat, and that the gas from the Massachusetts peat was better than the average of that made from the fifty-six samples of coal tested.

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[a] U. S. Geol. Survey Bull. No. 332, p. 28.

It follows from these comparisons that the types of American peat and those of foreign peat here cited were as good fuel in the gas producer as the kinds of coal tested, so far as the calorific value of the gas is concerned.

Another significant fact brought out by the tests made by the United States Geological Survey was that the single full test run made with peat as fuel in the gas producer gave results that surpassed, in the horsepower developed, those obtained from the best of the kinds of coal used in boiler tests. The same results were obtained in the shorter run in which Massachusetts peat was used. That is, more power was developed from a ton of peat converted into producer gas and used in a gas engine than a ton of any kind of coal gave in the steam engine during the entire series of boiler tests conducted under standard test conditions.

Although too much emphasis must not be laid on the results of a single experimental run or on two tests, manifestly the value of peat as fuel is greatly increased by the use of a gas producer. In the two cases cited, under rigid test conditions in a gas producer designed for a very different sort of fuel, the peat, with a calorific value ratio to bituminous coal of 1 : 1.8, gave more power by being gasified and then used in a gas engine than an equal weight of coal did by being used under a boiler to generate steam for a steam engine.

GAS-PRODUCER TESTS BY THE UNITED STATES GEOLOGICAL SURVEY.

The following is an account of the method of proceaure in tests of peat as a source of producer gas in the only complete trial of this fuel yet made by the United States Geological Survey. The account includes, however, the results obtained from both Massachusetts and Florida samples.

MASSACHUSETTS NO. 1.

Peat briquets from a bog near Halifax, Plymouth County, Mass. They were furnished by Prof. C. L. Norton, of the Massachusetts Institute of Technology, Boston, Mass., and shipped under the supervision of Mr. J. S. Burrows. The sample consisted of a small amount (less than 5 tons) of peat which had been macerated and pressed into bricks and then dried, and it was impossible to run a test of sufficient length to eliminate the factor of uncertainty. It was demonstrated, however, that a satisfactory gas could be obtained and no trouble was experienced in manipulating the load, but owing to the small supply of peat it was necessary to make the foundation of the fuel bed out of another fuel—Illinois coal. Considering this fact, and that the amount of peat furnished made it possible to conduct a test of only nine hours' duration, it is possible that the results as given below are somewhat erroneous. The figures are given for what they are worth, as they furnish an approximate idea of the possibilities of peat fuel in the gas producer, although they can not be regarded as official results. It is impossible to tell exactly what portion of the gas was due to Illinois coal and what portion to the peat alone.

The results of the tests of Massachusetts peat were as follows:

Producer-gas test—Test 97; Massachusetts No. 1.

Average electrical horsepower... 200.0
Average B. t. u. gas per cubic foot... 166.6
Total peat fired (pounds).. 6,480

	Peat consumed in producer per horsepower hour.		
	Peat as fired.	Dry peat.	Combustible.
Per electrical horsepower:	*Pounds.*	*Pounds.*	*Pounds.*
Available for outside purposes...............................	3.77	1.89	1.44
Developed at switchboard...................................	3.60	1.81	1.38
Per brake horsepower:			
Available for outside purposes...............................	3.20	1.61	1.22
Developed at engine.......................................	3.06	1.54	1.17

ANALYSES.

Peat:

Moisture................................ 49.80
Volatile matter.......................... 27.27
Fixed carbon............................. 10.88
Ash..................................... 12.05
                                        ————
                                        100.00
Sulphur................................. .34

Gas by volume:

Carbon dioxide (CO_2)................. 10.50
Carbon monoxide (CO).................. 22.50
Hydrogen (H_2)....................... 13.90
Methane (CH_4)....................... 2.10
Nitrogen (N_2)....................... 51.00
                                       ————
                                       100.00

FLORIDA NO. 1.

In connection with this test of a small quantity of Massachusetts peat, it is deemed advisable to refer briefly to a more elaborate test of peat bricks obtained from a bog located near Orlando, Orange County, Fla., on the Seaboard Air Line Railway, and designated Florida No. 1. The following notes are from Bulletin 332 of the United States Geological Survey:

This sample consisted of machined peat, made by a commercial process and sun dried, and was used in steaming test 386 and producer-gas test 117. By the process mentioned the peat first passes through a condenser, which disintegrates the material and destroys the fiber. From the condenser the peat is elevated to a molding machine, consisting of a cylinder and two vertical molding wheels. Through the cylinder passes a vertical shaft, to which are attached revolving arms set in a screw form. Between these arms are set perforated plates. The peat, passing into the top of the cylinder, is forced down through the plates to the molding wheel. From the molding wheel the bricks, which are 8 by 4 by 2½ inches, are dropped on boards or pallets, which are being continuously pushed under the machine by a link-belt carrier. These pallets, containing 6 bricks each, are loaded on wagons 50 to the load, and are hauled to the drying ground, where the bricks are allowed to lose from 60 to 75 per cent of their moisture content. The peat was furnished by the Orlando Water & Light Co.

Two samples were taken for analysis. Sample 3268 is raw peat just as it comes from the bog and sample 3269 is one of the bricks as it came from the machine before delivery to the drying ground.

Chemical analyses of Florida No. 1.

	Bog samples.		Car sample.a	Steaming test 386.b
Laboratory No...	3268	3269	3270	
Air-drying loss...................................	91.70	84.70	9.00	....
Proximate:				
Moisture..	92.41	88.40	21.00	17.21
Volatile matter..............................	4.68	7.28	51.72	51.01
Fixed carbon.................................	2.58	3.57	22.11	24.85
Ash...	.33	.75	5.17	6.93
Sulphur...	.05	.08	.45	.49
Ultimate:				
Hydrogen......................................	......	......	6.51	5.18
Carbon...	......	......	46.57	57.77
Nitrogen.......................................	......	......	2.33	2.89
Oxygen...	......	......	38.97	25.20
Ash...	......	......	....	8.37
Sulphur...	......	......	......	.50
Calorific value as received:				
Determined—				
Calories....................................	......	4,515	....	....
British thermal units................	......	8,127	....	....
Calculated from ultimate analysis—				
Calories....................................		4,338	....	....
British thermal units................	......	7,808	....	....

a Figured from sample from producer-gas test 117.
b Proximate analysis of fuel as fired; ultimate analysis of dry fuel figured from car sample.

In starting the producer-gas test (test 117) the fuel bed was built up entirely of the Florida peat and the usual preliminary run was conducted before the official test began. The total amount of peat consumed in the producer in the 50-hour run was 29,250 pounds, or 585 pounds per hour. The average calorific value of the gas produced was 175 British thermal units per cubic foot. During the entire run the average electrical horsepower developed at the switchboard was 205. The amount of peat used per electrical horsepower per hour available for outside purposes, including the estimated quantity required for the generation of the steam used in the operation of the producer, was 3.16 pounds, while 2.69 pounds were required per brake horsepower hour at the gas engine, available for outside purposes.

It should be stated that the peat bricks had been dried, and that the moisture content of those used averaged 21 per cent. The gas, as shown by the analysis, was rich in hydrogen and comparatively low in nitrogen. Following are the results of this test:

Producer-gas test—Test 117; Florida No. 1.

Duration of test (hours)...	50
Average electrical horsepower...	205
Average British thermal units per cubic foot of gas...................	175.2
Total fuel fired (pounds)...	29,250

	Peat consumed in producer per horsepower hour.			Equivalent used by producer plant.		
	Peat as fired.	Dry peat.	Combustible.	Peat as fired.	Dry peat.	Combustible.
	Pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
Per electrical horsepower:						
Commercially available................	2.98	2.35	2.20	3.16	2.50	2.33
Developed at switchboard..............	2.85	2.25	2.11	3.03	2.39	2.24
Per brake horsepower:						
Commercially available................	2.53	2.00	1.87	2.69	2.12	1.98
Developed at engine	2.43	1.92	1.79	2.57	2.03	1.90

ANALYSIS OF GAS BY VOLUME.

Carbon dioxide (CO₂).. 12.4
Carbon monoxide (CO).. 21.0
Hydrogen (H₂).. 18.5
Methane (CH₄)... 2.2
Nitrogen (N₂).. 45.5
Ethylene (C₂H₄).. .4

From these reports and from others of a similar nature, based upon much more extended trials in Europe, the ideal way in which to utilize peat for the generation of power would appear to be to convert it into gas in some of the types of gas producers that have been adapted to the purpose and to use this in properly designed gas engines.

PEAT AS FUEL IN THE GAS PRODUCER.

Wet, unprepared peat is difficult material to handle in a gas producer, first, because it contains so much water that the temperature of a mass of it can with difficulty be raised high enough to generate a fuel gas without consuming more fuel than is warranted by the results, and, secondly, because the raw peat tends to form dense, impenetrable layers in the fuel bed of the producer, through which the gases generated can scarcely find their way.

On these accounts the feasibility of trying to use raw peat in existing types of gas producers, except in a purely experimental way, is doubtful. For elementary experiments, successful gas production will be much more probable if the peat is machined, formed into small bricks, thoroughly air dried, crushed into pieces with an average diameter of 1 inch, and then used in a down-draft or pressure gas producer, although a suction producer with centrifugal tar extractor might be successfully used. It does not seem to be essential to have the pieces of regular form, nor is it desirable to have them more than an inch or two in largest dimension. Experience shows that if the pieces are too large the gas passes through the fuel bed too rapidly for the carbon dioxide to be decomposed; but with usual forms of gas producers very unsatisfactory results will be obtained by using the peat in a powdery condition.

There seems little doubt that some of the heat of the off-going gas can be utilized for drying the peat, and also that peat with a higher percentage of water than the air-dry state may be successfully used in gas producers of the type in which an excess of steam under pressure is used, such as the Mond producers of the Power-Gas Corporation (Ltd.), of Stockton-on-Tees, England. This company announces that peat containing 60 to 70 per cent water can be utilized by their process, and that there are three large installations already in operation, one in England, one in Italy, and one in Germany. The Mond gas producer has been modified by Frank & Caro, and by them it is claimed that peat with 40 to 60 per cent water may be used for fuel.

The use of the heat of the producer gas to partially dry the peat, although possible, must be carried on in such a way that the process is automatic and continuous, and that the water driven off does not accumulate in undesirable places. Many suggestions and designs of machinery for this purpose have been made, but the present European practice seems to be to adhere to the use of crushed air-dried machine peat.

The gas from peat gasified in ordinary gas producers contains much tar which should be removed in a tower scrubber with a spray of water, or in some of the more recently perfected types of scrubbers, because coke and other porous material used in ordinary scrubbers soon become saturated. The tar may all be decomposed, however, by using a down-draft producer, or as in the Koerting gas producer, by drawing the gases off at the top and conducting them by a special pipe to the zone of complete combustion, and thence up through the fuel bed. In such a producer the outlet for the producer gas is placed in the side of the producer at about the top of the incandescent layer.

COST OF GAS-PRODUCER POWER PLANTS.

For the following carefully prepared tables of cost of gas producers, producer-gas engines, and complete gas-producer power plants, the writer is indebted to R. H. Fernald, engineer of the Bureau of Mines, who had charge of the producer-gas investigations of the United States Geological Survey.

The following table gives the approximate price of suction, pressure, and down-draft gas producers of from 20 to 2,000 horsepower.

Approximate cost of suction, pressure, and down-draft gas producers of 20 to 2,000 horse-power.

Horse-power.	Cost of engine and auxiliaries f. o. b.	Cost of erection.	Foundation.		Total cost erected.	Cost per horsepower.	
			Cubic feet.	Cost.		F. o. b.	Total.
20					$923		$46.23
23					1,050		42.00
25	$650					$26.00	
35	800					22.80	
50	1,000					20.00	
60	1,360					22.70	
60	1,100	$150	50	$15	1,265	18.35	21.10
75	1,300					17.35	
100	1,500					15.00	
110	1,650					15.00	
110					1,900		17.30
150	1,850						
160			400	120	3,300		20.60
200	2,450					12.25	
200	2,500					12.50	
250	3,000					12.00	
300	4,300	960		150	5,410	14.35	18.00
500	9,500					19.00	
1,000	18,300	3,100				18.30	
2,000	23,066	3,700	2,140	555	27,321	11.50	13.66

The prices above are from quotations from various manufacturers, as is also true of the prices for the producer-gas engines below. It should be remembered that the cost of producer-gas engines is greater per rated power than the cost of engines of the same rating for natural or artificial gas.

Cost of producer-gas engines of 20 to 2,000 horsepower.

Horse-power.	Cost of engine and auxiliaries f. o. b.	Cost of erection.	Foundation.		Total cost erected.	Cost per horsepower.		
			Cubic feet.	Cost.		F. o. b.	Erected, excluding foundation.	Erected, including foundation.
20	$1,100	.....	.....	$50	$1,150	$55.00	.....	.....
55	.....	.....	.....	.....	2,400	.....	.....	$43.70
60	2,800	.....	350	105	.....	46.70	.....	.....
60	2,900	.....	.....	150	.....	48.40	.....	.....
75	3,610	$175	375	150	3,935	48.10	$50.50	52.40
80	.....	.....	.....	.....	3,300	.....	.....	41.20
80	3,400	.....	.....	.....	.....	42.50	.....	.....
80	3,250	.....	.....	.....	.....	40.70	.....	.....
80	3,830	.....	.....	.....	.....	47.90	.....	.....
85	4,150	.....	.....	.....	.....	48.90	.....	.....
85	3,550	.....	.....	.....	.....	41.80	.....	.....
100	4,925	.....	.....	.....	.....	49.25	.....	.....
110	4,950	.....	.....	225	.....	45.00	.....	.....
110	4,960	.....	.....	.....	.....	45.10	.....	.....
112	4,200	.....	.....	.....	.....	37.50	.....	.....
130	5,250	.....	.....	.....	.....	40.40	.....	.....
135	6,600	.....	.....	.....	.....	48.80	.....	.....
160	5,600	.....	.....	.....	.....	35.00	.....	.....
160	6,100	150	2,000	520	6,770	38.10	39.00	42.30
250	6,650	150	2,160	560	7,360	26.60	27.20	29.40
400	12,000	.....	.....	.....	.....	30.00	.....	.....
400	12,800	.....	.....	.....	.....	32.00	.....	.....
600	17,400	.....	.....	.....	.....	29.00	.....	.....
1,000	33,750	300	.....	.....	.....	33.75	34.00	.....
2,000	64,850	875	5,400	1,400	67,125	32.43	32.86	33.56

Weight of producer gas-engines per horsepower: Average, 300 pounds; maximum, 425 pounds; minimum 134 pounds.

Cost per horsepower of producer-gas installations.

Horse-power.	Cost of gas producer and engine.		Cost of complete plant.	
	Erected, excluding foundations.	Erected, including foundations.	Excluding buildings.[a]	Including buildings.
20	$105.00	$ 106.30	.....	.....
25	62.50	.....	.....	.....
60	69.50	74.00	.....	.....
75	86.50	.....	.....	.....
80	62.00	.....	.....	.....
110	60.50	68.00	.....	.....
110	62.50	.....	.....	.....
125	90.00	.....	$100.00	.....
250	65.00	68.00	79.00	$93.00
500	.....	.....	.....	.....
1,000	55.50	.....	69.50	79.50
2,000	46.00	47.50	56.50	63.30
2,800	.....	.....	.....	76.00
4,000	.....	.....	.....	69.00
4,000	.....	.....	.....	77.50
4,800	.....	.....	.....	72.00
4,800	.....	.....	.....	79.50
5,500	.....	.....	.....	70.00

a Includes producer, engine, electric generator, and auxiliaries, all erected with suitable foundations.

From the above it will be seen that the cost of a complete installation, with gas producers and producer-gas engines, is still somewhat more per horsepower than with boilers and steam engines, but seemingly the differences are decreasing. On the other hand, the cost of operating and maintaining a producer-gas plant is considerably less than for the steam plant of the same capacity, because the efficiency of the fuel is greater in the former. Less fuel and the ability to use the cheapest grades reduce the fuel bills, and labor charges are lower because less firing is needed, so that operating expenses may be decreased about 50 per cent.[a]

The chief matter of concern now is so to modify the types of gas producers used in this country that peat may be burned in them as successfully as in those used in Europe; the process of making producer gas is old and established, and engines for using the gas are already developed to a high state of efficiency and reliability.

BY-PRODUCT GAS PRODUCERS.

In Europe, where conservation and efficient utilization of natural resources have been practiced for many years, attention has been turned to the recovery of commercially valuable substances from the gases generated in gas producers and other apparatus for gasifying fuel without impairing the heat value of the gas, or of the other chief product of the distillation—for example, coke—if gas is not sought. Such secondary products are called by-products, and their recovery in charcoal, coke-making, or producer-gas plants may be of sufficient commercial importance to warrant the building of expensive equipment. The by-products obtained and obtainable depend upon the composition of the fuel distilled and the processes used to make the primary product, as well as upon the temperature at which gasification is carried on.

In general, it may be said that only three systems of by-product gas producers have been tried in Europe, two of which are still experimental. The Mond by-product gas producer for using bituminous coal is the oldest of these. This is designed to recover as ammonium sulphate a maximum proportion of the combined nitrogen in the fuel used. Ammonium sulphate, which finds a ready market for agricultural use is recovered in the producer by using large quantities of steam to keep the fuel at the lowest temperature at which the fuel gases can be given off. The ammonia was formerly made to unite with sulphuric acid in a special scrubbing tower, through which the gases from the gas producers were drawn by exhaust fans. The sulphuric acid towers have been entirely eliminated in the latest form of plant for recovering ammonia from Mond gas producers. The gas on

leaving the producer is cooled somewhat by passing through a tubular regenerator into a rectangular washing chamber. There it is washed with water in the form of a fine spray and freed from dust and part of the contained tar. The cleansed gas then flows through an apparatus in which the ammonia in the gas combines with sulphuric acid to form ammonium sulphate; this, in dilute solution, is withdrawn periodically.

This form of gas producer is said to be successful for large plants, and is in operation in many places in England and in one (Wyandotte, Mich.) in the United States. The other two by-product gas producers are the Ziegler and the Frank-Caro, both designed for using peat. The Ziegler gas producer recovers other substances besides ammonium sulphate, whereas the Frank-Caro gas producer is reported to be an adaptation of the principle of the Mond gas producer for using peat with a relatively high percentage of water, 40 to 60 per cent being allowable.

In the case of the Mond gas producer, large installations, at least 2,000 horsepower, are required to make economically possible the operation of the special peat gas producers for the recovery of ammonia, and plants developing 1,000 horsepower or more are mentioned as necessary to make the Frank-Caro process of ammonia recovery a commercial success. Therefore it seems probable that, as at present understood, the peat gas producer for ordinary power plants does not yield enough salable by-products to make their recovery in a special plant feasible, although the peat may run high in combined nitrogen. But small gas producers for using peat fuel are entirely practicable if no attempt is made to recover by-products from the gas.

PEAT REQUIRED FOR PRODUCING A UNIT OF POWER IN THE GAS PRODUCER.

The available records of experiments with peat in gas producers and of authentic statements of commercial operations show that it requires from 2 to 3 pounds of dry peat to develop an electrical horsepower per hour, the exact quantity being dependent, among other things, upon the type of gas producer, the efficiency of the producer-gas engine, and the quality and amount of moisture and ash in the peat used.

In one test run, the details of which are not available for publication, the peat as put into the gas producer contained 27.8 per cent ash and 13.9 per cent moisture, yet only 4.11 pounds were consumed per hour for each commercially available electrical horsepower, or 3.5 pounds estimated as dry fuel. Stated in another way, 2 tons of air-dried machine peat of a grade too high in ash to be considered within the limits of ordinary commercial use for boiler fuel would run a

100-horsepower plant for one 10-hour day, if the gas produced were used in a gas engine designed for this kind of gas. It may be said that the experiment cited was conducted under rigid test conditions, and although, because of probable and uncertain impoverishment of the gas through leakage, the details of the run can not be published, the figures quoted may be taken as the maximum for this type of producer and fuel.

UTILIZATION OF PRODUCER GAS FROM PEAT.

Mention has been made of the use in European countries of producer gas as a fuel in certain industries. The energy of the peat may be economically and satisfactorily utilized as gas by using the proper forms of burners for firing [a] steam boilers, ceramic kilns (brick, tile pottery, etc.), lime and cement kilns, metallurgical furnaces (forges, foundries, steel and ore roasters), and muffle and glass furnaces.

Peat fuel properly prepared is especially valuable for metallurgical work of all sorts, because it contains less sulphur than coal or coke. The same may be said of the gas derived from peat. However, beds of peat that have been subjected to the action of salt or brackish water, or to certain kinds of spring water, are exceptions to the general rule. These may have as much sulphur as many kinds of coal, and at least a part of the sulphur will appear in producer gas generated from such peat.

Gas producers for fuel gas are usually of the pressure type. The special use for which the gas is required should determine the form of the producer and the kind of scrubbing apparatus employed. The form of the producer and the scrubber must also be adapted to meet the peculiarities of peat if this substance is to be used for making fuel gas. In some cases where producer gas is required as fuel, no cleansing would be required, but the gas would be conducted directly from the producer to the burners. The form of the furnaces or kilns in which the use of peat gas is proposed and the manner of firing them will have to be adapted to the requirements of the product and of a gaseous fuel. Moreover, workmen must be trained specially in order to get the best practical results.

In general, it may be said that the attempt to develop plants for utilizing gas for fuel should be left to trained experts in gas engineering and to concerns with large capital, as much well-planned and carefully conducted experimental work will usually be needed before anything like the theoretical efficiency is obtained in actual practice from such processes and the plants using them. It should be said, however, that all or nearly all of the uses suggested as possible for producer gas as fuel have been tried on a commercial scale, and are

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a Wyer, S. E., Producer gas and gas producers, 1907, p. 210.

embodied in plants now in operation in the United States or Europe. There seems to be no doubt, also, in view of the facts already stated, that a good quality of producer gas can be cheaply made from peat for any of these purposes, if properly designed and well-constructed gas producers are used at a place where a supply of peat is available.

GENERAL CONCLUSIONS ON PEAT FUEL.

FUEL VALUE.

The fuel value of peat as compared with that of coal and wood for firing boilers, furnaces, and stoves has already been discussed at length (pp. 52–64). The facts presented would seem to demonstrate that although plainly inferior to the best coal in the number of heat units yielded per pound consumed, nevertheless, if prepared in the ways commonly used in Europe peat fuel presents so many desirable qualities, such as freedom from smoke, cleanliness in handling, small ash content, complete and easily controlled combustion, and prospective low price, that there should be a good field for its introduction for manufacturing and domestic uses in those parts of the United States where peat naturally occurs in abundance.

UTILIZATION OF DEPOSITS.

There are many small bogs in the peat-bearing regions of the country which, although too small to warrant the establishment of large plants for the production of fuel, could be utilized to furnish machine peat enough for boiler fuel for a single small factory for many years. They might also furnish the power to pump water and generate electricity for a small community for an equal length of time.

The principal matter to be borne in mind in preparing to exploit a peat deposit in such a way is that the simplest equipment which has proved it can yield the desired quantity of usable or salable fuel is the one most likely to give satisfactory returns either in fuel or money. Every added process of treatment beyond that which is necessary to put the peat into usable form for a specific purpose adds many times to the first cost of equipment and to the practical difficulties of making a product that can be sold for enough to pay the costs of preparation and of putting it on the market at a profit.

PRODUCER-GAS PLANTS.

The present state of knowledge seems strongly to indicate that large peat deposits can be most profitably utilized, and the largest percentage of the stored-up energy in them recovered as power, by converting the peat into producer gas and using this gas in properly

designed gas engines. The power may be used by factories operated on the spot, or as electric energy may be used at a distance. Large plants, by using by-product gas producers and thus at least recovering as ammonium sulphate the ammonia that is formed during the destructive distillation of the peat, may be able from sales of the sulphate to pay a part of the expenses of the whole operation The by-products process, however, may not be feasible for gas-producer plants of small size, because the costs of installation, maintenance, and supervision are proportionately higher for small than for large plants, and the quantity of by-products obtainable from a small gas producer is not sufficient to keep a recovery plant in operation continuously.

Even without any by-products the use of producer gas presents so many advantages that wherever peat beds are to be used as sources of fuel for power installations of more than 100 horsepower, the possibilities of a producer-gas plant should be given serious consideration.

· The producer-gas plant may also be readily adapted to metallurgical work, to firing kilns for brick, porcelain, lime, and probably for cement manufacturing. It might have a large use in roasting ores and, in a smaller way, in foundries and other iron-working plants, and in reheating and refining steel, copper, and other metals when fuel free from sulphur is required.

Even for boiler plants that could use peat fuel, a gas producer would be a most desirable adjunct, as it would permit the use of peat less carefully prepared and containing more water, and the economy would be greater than in any other way of firing.

PEAT POWDER.

Next to producer gas, peat powder is the most attractive form of fuel for firing boiler furnaces, for operating kilns of various sorts, and for the metallurgical operations mentioned. This form of peat fuel has not yet been so generally used in Europe as has producer gas, and not as much has been demonstrated commercially in regard to its value. The most recent reports are very favorable and indicate that peat powder can be cheaply produced and is as good fuel for boiler firing when properly prepared and fired as the same weight of good English coal.

DOMESTIC USES.

The steadiest and, in the aggregate, the greatest demand for peat fuel may be expected to come from small consumers who want a clean, easily handled, and cheap fuel that gives out a steady heat and yet responds quickly to changes of draft when burned in ordinary

heating and cooking stoves. Doubtless in this way, as a supplementary and auxiliary fuel, much of the peat that is gathered for fuel will be used.

PEAT COKE.

Peat coke is the most efficient solid fuel derived from peat, but its high cost of preparation will doubtless limit its use even more than that of charcoal is now limited. Its value for all uses to which charcoal is now put should find it a ready and satisfactory market after it has once become known to the industries that require such a product.

PEAT AS A RAW MATERIAL FOR PRODUCTS OTHER THAN FUEL.

For many years the peat beds of Europe have been studied to see if the great quantities of partly decomposed, fibrous plant remains that are found in them, and that can be recovered seemingly at low cost, could not be made into articles of commercial value which would replace those now made from more expensive materials.

It must be borne in mind, however, that most kinds of vegetable raw materials are scarce in the countries of northern Europe where this experimental work has been carried on, and command a much higher price there than can be obtained for similar materials in the United States. There is, therefore, a much greater incentive to find substitutes or adulterants there than in this country, where potentially valuable vegetable substances are extravagantly used or allowed to go to waste. Material better than peat for some of the uses that have been proposed for it in Europe is at the present time wasted lavishly in some parts of the United States where peat is found, or in nearby territory.

CHEMICAL PRODUCTS.

In discussing the manufacture of peat coke and peat gas in preceding sections, the possibility of obtaining a variety of chemical substances of commercial value was brought out. These materials are actually made on a commercial scale in Europe as by-products of peat-coke plants by condensing and redistilling the heavier gaseous products of distillation. In this country the same compounds are obtained as by-products of making charcoal, and to a rapidly increasing extent some of them are recovered from coal-coking plants and illuminating-gas and power-gas producers.

The recovery of chemical by-products from the destructive distillation of any fuel requires a carefully planned recovery plant, so designed and arranged that it will handle automatically, at the least possible expense, large volumes of liquids, containing a small percentage of salable material; to do this the greatest possible economy of heat and power must be effected. In addition, the cost of supervision and of skilled labor necessary for such recovery plants is considerably greater than for plants making less complicated products. For these reasons the manufacture of acetic acid

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and acetates, wood alcohol, formaldehyde, ammonia and its compounds, phenol and creosote compounds, and the products which can be derived from the tarry residues from peat distillation, such as illuminating and heavy oils, paraffin wax and asphaltum, can be profitably undertaken only at large plants, well designed and constructed, sufficiently capitalized, and properly managed.

It is significant that several plants erected in connection with large lumbering operations, for utilizing waste wood, by distilling the lighter compounds mentioned above, have not been successful. The reasons for failure have not been that the products were not in demand at good prices, or that there was any inherent difficulty in any of the processes, but that so far as could be learned, the margin of profit was so small, and the expenses of maintenance so great, that the owners preferred to close the plants and waste the materials which they attempted to save or to convert them to other uses.

There seems to be no question whatever, from the reports published, that all of the chemical compounds which have been mentioned can be profitably made from peat, and that there is a market for many of them in large and increasing quantities, but it seems assured, also, that they can be made with profit only in large and costly plants in which charcoal or coke is obtained from the peat as the principal product, or in those in which large quantities of peat are gasified to generate fuel or power gas.

ALCOHOL.

Within a few years there has been a revival of interest in a process by which ethyl or "grain" alcohol can be obtained from peat. It has long been known that cellulose could be broken down into sugar by proper chemical treatment, and that the sugar could be converted into alcohol by fermentation induced by yeasts, as in the ordinary production of alcohol from cereals and fruits.

The revival of this process was reported from Denmark, Sweden, and France, where experimental factories were established to test a newly discovered yeast, and from them came the reports that alcohol could be made from the coarser and less decomposed types of peat, at a total cost of between 45 and 50 cents per gallon.   Later accounts state that the Danish plant has closed indefinitely without commercial operation.

The process of making alcohol from peat, therefore, is still in an experimental stage.   It may never reach the point where it will be used in this country, as in many communities apples and other fruits rich in sugar and sugary waste of various kinds are allowed to decay in large quantities when, for a smaller cost than peat can be used, they might be converted into alcohol for fuel uses.

AMMONIUM COMPOUNDS.

THE FRANK-CARO PROCESS. [a]

The process of Frank and Caro for obtaining ammonium sulphate as a by-product incidental to the development of producer gas from peat has been mentioned in the discussion of producer gas. From 70 to 85 per cent of the combined nitrogen of the peat, often amounting to more than 2 per cent of its dry weight, is recovered by this process.

The peat, which may contain from 40 to 60 per cent of water, is superheated with an excess of steam in the drying zone of a Mond gas-producer, decomposing the nitrogenous compounds and converting part or all of them into ammonia. The steam and gases from the producer are conducted through pipes to washers and ammonia-fixing apparatus, where the free ammonia in the gas is brought into intimate contact with sulphuric acid and converted into ammonium sulphate. The dilute solution is periodically drawn off at the bottom and concentrated by evaporation. It may be filtered and purified by crystallization. This process is reported by Caro [b] to be in use at Sodingen, Germany, and at the large peat electric power station of the Hanover Colonization and Moor Improvement Co., at Schweger Moor, in northwestern Germany.

Ammonium sulphate has a rapidly increasing demand because of its high value as a constituent of the best types of fertilizers, and the cost of equipping a plant of sufficient size to profitably manufacture it from peat on a commercial scale is the chief factor to be considered by those contemplating its production.

THE WOLTERECK PROCESS.

By the Woltereck process, which is the discovery of Dr. H. Woltereck, of London, England, the discoverer claims to get a part of the nitrogen for the ammonia directly from the air and only a part from the peat. This claim is backed by the reports of a long series of carefully conducted laboratory and large-scale experiments, which have been worked out seemingly with great scientific accuracy and attention to detail. The assertion is made that when wet peat is burned in a specially constructed furnace at a temperature barely sufficient to keep the fire alive, some of the nitrogen of the moist air, constantly forced into the combustion zone of the furnace, forms ammonia by uniting with the hydrogen of the organic matter that is being decomposed. The gas from this wet combustion contains tar, tar water, and other distillates from the peat, besides the ammonia. In a large plant now in process of development in Ireland these

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[a] See also section on by-product gas producers, pp. 158-159.
[b] Caro, N. Chem. Zeit. 35: 56: 506-7, 1911.

gases are conveyed from the furnace to a scrubber that removes the tars without condensing the water, as this water would contain a part of the ammonia. From the tar scrubber the hot gases are sent to an alkali tower, where a hot solution of soda or milk of lime removes the acetic acid, as sodium or calcium acetates. The acid may be recovered by later treatment. The gas next passes to similar towers in which it is met by a fine spray of hot, dilute sulphuric acid, which combines with the ammonia to form ammonium sulphate, the chief object of the process. The acid is used until nearly or quite neutralized, when the solution of ammonium sulphate is drawn off to crystallizing vats, concentrated by evaporation, and purified by crystallization.

The process gives no fuel gas, as the temperature at which the peat is burned, 750° to 950° F. (400° to 500° C.) is too low to permit the formation of carbon monoxide or hydrogen. The process is consequently one purely of chemical manufacture, based on the formation of ammonia from the nitrogen of the air and of the peat itself, by the slow combustion of wet peat, the statement being made that peat with 75 per cent of water can be successfully used in this way.

The plant for manufacturing ammonium sulphate by this process must be of large size to be profitable, because, as in other chemical industries, the cost of production increases disproportionately as the output is decreased. The inventor of the process estimates a minimum production of 5 tons of ammonium sulphate from 100 tons of theoretically dry peat. The plant now being erected in Ireland, it is estimated, will manufacture at least 5,000 tons of ammonium sulphate per year when in operation, besides acetic acid, paraffin, and other chemical products of secondary importance. The cost of constructing the plant now being built will be approximately £100,000 ($500,000). If, however, the discovery is as stated, this investment is justified by the needs of the agricultural interests of the world, which are making constantly increasing demands for more sources of combined nitrogen suitable for fertilizing purposes.

<div align="center">NITRATES.</div>

Peat has also been proposed as a means for the intensive production of nitrates on the following principle pointed out by Muntz and Laine. A culture bed of peat, watered with a dilute (0.75 per cent) solution of ammonium sulphate, then inoculated with nitrifying organisms and kept at a temperature of 38° C., yields, after a time, nitrates to the amount of 0.82 per cent. By repeating the application of ammonium sulphate five times, the quantity of nitrates developed amounts to more than 4 per cent. This may be washed from the bed and purified. The peat may then be used for fuel or for distilla-

tion. Whether this process is adapted to the commercial production of nitrates on a large scale is not yet demonstrated, but in view of the rare occurrence and limited supplies of these salts, so vitally important in agriculture, it presents possibilities of great importance if the facts relative to nitrogen fixation are as stated. The fact that all of the world's supply of grain alcohol is obtained by the action of microorganisms on sugar solutions, often of considerable dilution, points strongly to the conclusion that no great difficulty would be met in applying to commercial operations the principle stated by the authors quoted. If, however, the only change effected is to convert to a nitrate the nitrogen compound supplied to the peat from ammonia, the value of the process is questionable.

DYE STUFFS.

The well-known brown color of water flowing from peat deposits may be greatly increased in strength by adding alkaline substances to wet peat, as they dissolve some of the organic acid compounds. The resulting brown compounds can be again precipitated as insoluble substances that are said to give a permanent brown color and that could probably be utilized as dyes. The color can also be obtained in the form of a brown powder by adding an excess of acid to the alkaline solution first obtained and filtering.

MATERIALS FOR TANNING.

Tanning materials have been obtained in Europe from peat. It has long been known that peat, especially those types in which woody plants were abundant, contains tannic acid, tannin, and related substances in considerable quantity. The process of preparing the tanning material is thus described by Ryan:[a]

The powdered peat is treated with nitric acid in cemented cisterns until a small part of the product ceases to give brown fumes when boiled with an excess of nitric acid. The mash is then diluted with water and heated by a current of steam for several hours. A solution of stannous chloride is added, and the boiling is prolonged until the dark color of the solution has changed to a light brown, when the liquid is decanted from the precipitate and can be used directly for tanning hides.

Other chemical products that can be obtained are discussed in the sections of this bulletin relating to peat coke.

PAPER.

Peat containing much fibrous matter has been manufactured into paper, chiefly in a single factory established for the purpose at Capac, Mich. The machinery was invented in Europe, but has been brought to perfection in this plant, which was reported by the owners to be the only one in the world at the time it was erected.

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a Ryan, H., Reports upon the Irish peat industries, p. 415.

The product thus far manufactured is cardboard of a dark color but good quality, suitable for making boxes and for similar purposes. The raw material can be bleached, but seemingly the coloring matter of the peat is so durable as to render bleaching too expensive for commercial purposes.

In 1910 a small plant for making coarse brown paper from peat mixed with wood pulp and other paper stock was erected near Garrett, Ind. The product finds ready sale.

The chief objections to using peat as paper stock can be briefly stated as follows: There is much waste material, including water and mineral matter, which must be handled before it can be eliminated; peat is usually uneven in structure and texture; the fibrous matter is small in quantity, was originally poor in texture, and has been weakened by decay. Hence the peat fiber often has to be enriched with wood pulp or other paper stock to produce even poor grades of paper. The fiber is also difficult to bleach, so that only coarse brown papers and cardboard can be manuafctured. Most types of peat contain very little fiber and are too thoroughly decayed for use as paper stock, and it is probable that less than 10 per cent of the peat deposits of the United States are suitable for paper making.

Probably the only kind of bog that may be considered suitable for this purpose is one which has been built up from the bottom by successive layers of grasslike plants to a considerable depth and over a large area. Poorly decomposed moss peat, by the addition of a small percentage of paper stock, might be used for making some grades of paper. The bogs with a 3 or 4 foot stratum of mossy, fibrous, or woody peat at the top and structureless material below would be of small value for paper making, nor would those of small area be available, since the cost of equipping a paper mill is large.

Paper and pasteboard made from mixtures of varying quantities of peat fiber and wood pulp have been produced from time to time in several countries of Europe, where a considerable number of processes have been patented, but generally the manufacture has not been continued beyond the experimental stages because of the high costs of reducing the peat fiber to a condition suitable for use.

WOVEN FABRICS.

The stronger fibers from the more fibrous kinds of peat may be separated and cleansed from the surrounding material, and after treatment which renders them pliable they may be woven into fabrics. The most successful experimental use for this kind of cloth has been as blankets for horses and other live stock.

It has been reported recently from Europe, also, that the fiber obtained from the remains of the sedges that frequently grow in moss bogs is collected by hand as the peat is run through disinte-

grating machinery, and is used for adulterating silk threads and fabrics, for which purpose it is in growing demand. After the material is sorted, or in the case of purer fibrous peat without such sorting, the entire mass is beaten up with water, after which the fibers are gathered by means of forks moved by an endless chain. The fibers are removed by the conveyor to large vats, in which they are washed with water, again collected, party dried, placed in hot acid solution, washed, and allowed to ferment, and then dried. The dust which still adheres to the fibers is next removed by proper screening, and the cleansed fibers are prepared for spinning. The cost of this material is about the same as that of hemp and flax, about twice that of jute, and only a little less than that of cotton, even in Germany, where it is produced.

ARTIFICIAL WOOD.

A material called " Heloxyl," closely resembling heavy paper, was made by compressing fibrous types of peat and hardening the resulting material by special treatment into sheets, blocks, and other forms for structural purposes. The material was light, compact, waterproof, and nonconductive of sound, vibrations, and heat, and could be made fireproof by the introduction of mineral matter; it was also readily glued, nailed, and painted, and because of these properties, as well as its strength and lightness, made good finishing material.

Artificial wood, made by mixing fibrous peat with certain mineral cements and compressing it, has also been made in a small way in Germany. The material can be molded into any desired form, is noncombustible or slow burning, does not absorb water, and is so tough and hard that it is said to make good and durable paving blocks and flooring, as well as a desirable substitute for wood in most of its ordinary uses.

MATTRESSES AND SANITARY APPLIANCES.

Moss peat and material which has been selected and cleansed of sticks and other coarse matter, or the roughly cleaned fibers derived from peat, may be made into mattresses and dressing for wounds.

The absorbent, deodorizing, and antiseptic properties of peat make it good material for these uses. The mattresses are said to be especially valuable for hospital use, since they are light in weight, resilient, soft, inodorous, and very cheap, so that they can be renewed at small cost.

The material used for dressing wounds needs more thorough preparation than that intended for mattresses, as it must be freed from all dirt and woody matter, and, on the whole, there is doubt whether it possesses sufficient superiority to substances now in general use for

the same purpose to warrant trying to introduce it.   In the form of fine powder it has been used with excellent results in dressing cuts, burns, and other wounds, and its many good features for such use merit investigation by American surgeons.

MOSS LITTER AND MULL.

A much more general use for the more fibrous kinds of peat in Europe is for bedding for stock, and in the form of powder or mull for various packing, absorbent, and deodorizing uses.

Moss or peat litter is hardly to be classed as a manufactured product, since the common processes of manufacture consist chiefly of cutting the peat into large blocks, spreading them on the bog to dry, gathering the peat blocks in a partly dried condition, and tearing these up by the use of simple machinery.   The shredded material is passed through rotary screens to separate the finer material, or mull, then dried artificially and packed in bales.   This material is capable of absorbing much larger amounts of moisture in proportion to its weight than any other substance in general use for stock bedding. It is a good deodorizer, and almost entirely prevents the decomposition of the nitrogenous and other organic substances for a considerable time.   In addition, it is reported to be springy and durable and to keep the feet of the animals which stand on it in perfectly healthy condition.

At the present time a considerable quantity of this sort of litter is imported from Holland and other countries of northern and western Europe; in 1909 it amounted to something over 9,000 tons.   It has been made for several years past at a single plant at Garrett, Ind., and the demand for the product of this establishment is rapidly increasing.

Many of the peat bogs of the northern United States are favorably situated for manufacturing this material, and the peat is admirably adapted for the use, judging from the imported product that has been examined by the writer.   This substance is chiefly composed of poorly decomposed sphagnum moss and other herbaceous plants, and is of a light-brown color when dry.

COST OF A PLANT.

The cost of equipping and establishing a plant for making moss litter is not large when compared with that of the more complicated fuel-making plants, because the machinery is inexpensive and of considerably lighter construction.   For larger plants some form of efficient artificial drier should be provided to complete the drying of the peat after it has dried as much as is possible on the surface of the bog.   To dry the peat below 15 or 18 per cent of moisture before

baling, however, will be entirely unnecessary, as when dried below this water content the peat will rapidly take up moisture until it contains as much as it can absorb from the air—from 10 to 20 per cent, according to the relative humidity of the air in the locality.

Following is a statement of the cost of a moderate-sized plant equipped with European machinery, but without drier or boiler and engine:

Cost of machinery for a peat moss litter and mull factory producing from 1 to 2 tons per hour.

Description of machinery.ᵃ	Weight.	Net cost, f. o. b. New York.
	Pounds.	
Disintegrator, consisting of double driving, 2 driving wheels, 2 pulleys, 2 rollers with exchangeable tappet rings of steel, mounted on iron scaffold........................	4,000	$1,000
Chain elevator, consisting of a forged bucket chain, upper driving, guiding stations, and lower expansion gear.........................	2,000	675
Rotating sieve for sifting off the litter and at the same time producing mull..........	1,500	500
Latest bale press of bar or rack and pinion jack, for any size of bale; driving coupled with machine, including an automatic brake, 2 pulleys, and self-acting starter.....	10,000	2,500
Complete transmission for above, including all pulleys, bearings, lubricators, and belts...	2,500	1,200
The required foundation pins, bolts, and fastening screws.........................	650	125
		6,000

ᵃ For a full description of peat-litter plants see Nystrom, E., Peat and lignite; their manufacture and use in Europe: Canada Department of Mines, Mines Branch, 1908, p. 231.

MARKETING AND USE.

The litter, after preparation, is shipped in highly compressed burlap-covered bales, and brings a good price in the markets—generally a much better one than could be obtained as the result of the same expenditure of time in preparing the same weight of peat for fuel.

Peat litter should not only have a large use in city stables, but ought to be used in dairy barns, where its absorbent, deodorizing, and disinfecting properties would make it much more valuable than any material now commonly used for the purpose.

The mull, consisting of the finer parts of the peat screened out from the litter, is much used in those European countries where it is produced as an absorbent and cheap deodorizer. It is very satisfactory for use as a substitute for more expensive chemical substances or mixed with them for outhouses, earth closets, cesspools, etc., in places where comprehensive sewer systems have not been constructed.

On the whole, these products, simple as they are, and requiring no large outlay of capital, present the greatest possibilities for paying investment to owners of peat deposits of suitable character, because they are easily and cheaply made, are already on the market, and are favorably known to many dealers and consumers.

PACKING MATERIAL.

Peat prepared in about the same way as the moss litter is largely used in Europe for packing fragile and perishable articles, and there seems no reason why it can not be used for the same purposes in this country, where much more expensive substances are now employed. This use should be extended to include the packing of eggs, fish, meats, and fruits, as is done in Europe, for cold storage. The antiseptic power of the peat adds to its value for this purpose. An exhaustive series of carefully planned experiments with the proposed packing material in various forms and with varying water content under American conditions is needed before any considerable investment for producing it on a commercial scale in the United States can be recommended. Peat moss (*Sphagnum*) is gathered and baled in considerable quantities in New Jersey, and to a less extent in New York, for packing and for florists' use.

FERTILIZER FILLER.

The most extensive and successful use of peat as the base of a commercial product sold in large quantities on the open market in this country is as "filler" in artificial or chemical fertilizers. This filler should not be regarded, however, as a harmful adulterant, but rather as a diluent, or in some cases as a necessary constituent of the mixture into which it is introduced, since it improves the whole, both mechanically and chemically; for the same purpose manufacturers use powdered graphite, coal dust, cinders, and ashes, sand, etc. The use of peat powder as filler also permits the use of many kinds of waste animal matter, rich in valuable nitrogenous compounds, which could not be used otherwise because they absorb water from the air and cake, or give off offensive odors, and soon decay, their valuable nitrogenous contents being dissipated as gases.

On the other hand, the peat adds to the total nitrogen of the completed fertilizer, so that an analysis shows a certain proportion of nitrogen, which is said by chemists not to be immediately available for plants, and as nitrogen is the most costly constituent of all fertilizers, this addition is objected to by some agricultural chemists. Recent experiments seem to show, however, that at least one-third of the nitrogen in even poorly decomposed peat is really immediately available for plants, hence part, at least, of the objections to this use of peat fall. The advocates of its use claim that it improves the mechanical texture and the odor of the mixtures in which it is used, and prevents the loss of nitrogen by checking the decomposition of its organic compounds and by absorbing any free ammonia developed; it also adds to the soil an amount of organic matter equivalent to the

quantity of the peat used, the decomposition of which gives plant food and increases water-holding capacity. The black, well-decomposed kinds of peat from thoroughly drained bogs are most often used for this purpose; such soils often show great and lasting fertility, producing good crops year after year with little fertilization, thus showing that they have an abundance of plant food.

The processes of preparing peat filler are even simpler than those for peat litter. The peat is dug or plowed up and allowed to drain and become as nearly air-dry as may be, after which it is dried artificially, often in a rotary drier, to a low moisture content, ground into a powder, and shipped in bags or in bulk. The grinding may be done before the artificial drying. The blacker, more highly decomposed peats are most sought for this use because they generally contain a larger percentage of nitrogen than others.

To be well equipped for the production of peat fertilizer filler a plant should require as little manual labor as possible. The equipment should include machine diggers, cars, and portable tracks for transporting the peat to the stock piles or storage sheds, and mechanical conveyers for transferring the crude, partly dry peat from storage to the driers.

The commercial success of the entire operation may depend on the completeness of the mechanical arrangements connected with the drying plant. These, in such a plant, take the peat to the driers, receive it after drying, and remove it automatically to storage rooms or to cars for shipment.

Because of the varying conditions of drainage at the different plants producing peat filler, different methods of digging the peat and of treating it before artificial drying are used. At some plants hand labor is used exclusively to dig the peat from drained or partly drained deposits and to place it on tramcars by which it is removed immediately to stock piles.

At other plants operating on wet or undrained deposits the peat is dug by dredges floated in canals of their own excavation. As fast as the peat is dug it is either piled on the bog to drain, or on cars running on portable tracks along the bank of the canal, or on scows which are floated on the canal to the drying grounds or the factory for unloading.

On thoroughly drained bogs that are dry enough to permit cultivation the peat is sometimes plowed and harrowed before the upper layers are scraped up. Such treatment reduces the peat to powder and hastens drying materially. Every pound of water removed by evaporation induced by the wind and the heat of the sun reduces the amount of fuel needed in artificial drying. It is, therefore, where possible, a distinct advantage to treat the peat as described.

A modification of the method of cultivation just described is in use at some peat-filler factories. The digging, spreading, and gathering machinery described in an earlier section (p. 113) is used to prepare and gather peat powder with less than 40 per cent of moisture from the drying fields a few hours after digging—a great advantage, as may be seen by reference to the table showing the relations of the weights and percentages of the water contained in peat (p. 110).

It is doubtful whether peat containing more than 50 per cent water can be dried with profit by artificial heat in the form of drier generally used, considering the prices generally received for the product.

A fully equipped plant for making peat into fertilizer filler probably costs more than a plant for making machine peat, but because of the established market a good product of sufficient weight and of high nitrogen content commands a ready sale at considerably higher prices than the peat would bring as fuel in the form of machine peat.

Peat fertilizer-filler plants were operated in 1910 in Florida, New Jersey, Massachusetts, Pennsylvania, Ohio, Indiana, Michigan, and Illinois.

PEAT AS A FERTILIZER.

Experiment has seemingly demonstrated that powdered black peat that is somewhat alkaline in its reactions may, if properly prepared, be used with much benefit as a fertilizer on soils lacking in organic matter. Such material has been put on the market as a lawn dressing, and is finding a ready sale. Peat for this use should have a high nitrogen content, and the organic matter should be in such form that plants can get it readily. Fibrous and brown peat have little, if any, value for this purpose, and should not be used where immediate results are expected. The experimental work which has been done on the fertilizing value of peat has been too limited to warrant final conclusions, but the experience of farmers for many generations seems to justify the use of peat as a fertilizer.

CONCLUSIONS.

Peat is available for any of the uses cited in this discussion and for some others which have not been considered here, but it can hardly be classed as a satisfactory raw material for making any of the more complicated products under the usual conditions existing in the United States, where other and established substances are already to be had in any desired quantity and at satisfactory prices. Moreover, these products are obtained from peat only by large investment of capital, and in most cases can not be manufactured before the plant has passed through a long experimental period, which must be properly provided for by a considerable reserve fund.

The simpler products, peat litter, mull, mattresses, packing material, and peat-fertilizer filler, have a much greater chance of being quickly made profitable, because some of them are already on the market and present uses for which the peat is especially adapted. Moreover, the processes of preparation are simple, and the cost of equipment for their manufacture with tried machinery is so low that moderate expenditure will fully equip a plant for their manufacture, and a long experimental development is unnecessary.

It is apparent, therefore, that the more fibrous kinds of peat, where they are abundant in the United States, may be put to a number of profitable uses besides making them into fuel, while the black, plastic types have other possibilities, although they are not adapted to the same uses for which the first-mentioned type may be recommended.

AGRICULTURAL USES OF PEAT.

The utilization of peat in agricultural operations is a topic of importance to the farmers of the regions of the United States where peat deposits are common, especially where reclamation by drainage is being undertaken, and this is beginning to be realized by those who are working on the problems involved in increasing the rate of yield and the diversity of farming operations. The subject of the proper value of peat and peat lands to agriculture is so important and so complicated that it can be fully discussed only after a great number of practical experiments on a large scale have been made to deter-mine the availability of this sort of land for various kinds of crops under the wide range of temperature, of rainfall, and of types of peat that exists in the United States.

In Europe, partly because of the large areas of unproductive peat land in the agricultural countries, and partly because of the crowded condition of these countries, the qualities of peaty soils have been made for many years the subject of exhaustive and careful study by trained specialists.

These generally work under the auspices of a society made up of farmers, landholders, and others who are interested, and aided by definite appropriations of funds by the Government. The Government further aids in this important work by establishing and maintaining experiment stations at peat bogs, where the necessary experiments as to culture, drainage, and other phases of the problem are systematically carried out on such a scale that their practicability as well as their desirability may be determined. Government aid and supervision is given to plans for the colonization and development of large areas of marsh lands and in Germany a number of such colonies are now established.

No work of this sort has yet been attempted in the United States except at a few of the State agricultural experiment stations, where investigations of the value of peat as a fertilizer and as a soil for certain crops are now being carried on.

PEAT SOILS.

In its natural condition peat is too wet to be worked, and before any crop plant can be made to grow upon it the surface must be cleared and the water level lowered by effective ditching and draining. In

general, after this has been accomplished, the surface layers of the peat are coarse in texture and often full of partly decayed stumps, roots, and other woody débris, which must be removed.

The coarse-textured peat dries out readily and affords only a small amount of plant food, so that after a short time, or during unfavorable seasons, crops fail. Often swamps are cleared, drained, and cultivated for a brief period at considerable expense and then abandoned because they are, as a rule, unproductive.

Aside from the coarseness of peat soils and their consequent poverty of moisture and plant food, an important cause of crop failure seems to be the attempt to grow crops not adapted to the soils. Extended observation in various parts of the country where peat soils are common seems to indicate that after one or two crops have been taken from newly cleared peat land of the common kind, grass is most likely to yield good crops for a number of years until the surface layers are blackened and disintegrated into a fine-grained, homogeneous mass. After this has been accomplished, various kinds of crops may be raised, but these, as a rule, should be such as can well endure cold nights and early frosts, and are not greatly injured by drought. Various truck crops, such as onions, lettuce, celery, cabbage, and other vegetables, seem to thrive on well-blackened peat and often yield very large returns.

Peat soils generally need mineral fertilizers, especially potash, because they contain little available mineral matter, and barnyard manure is often very effective in adding to their productiveness, both because it adds to the peat material which the latter lacks and because, seemingly, it promotes the decomposition of the peat by introducing the fungi and bacteria which cause decay and hasten humus formation.

In some parts of the country peat soils are among the most productive of any, yielding large crops year after year with no more care than is required to obtain inferior crops from other kinds of soils. In such places, however, the peat is of the thoroughly decomposed, black type, generally known as "muck"; the brown, fibrous kinds are seldom very fertile until they have been cultivated or exposed to weathering agents for some years.

FERTILIZER.

Muck, or peat, has long been used by farmers as an auxiliary fertilizing material, either directly applied to the land or applied in connection with other fertilizers, especially in composts with barnyard or stable manure. This practice is justified by the composition of peat, some kinds of which contain from 2 to 3 per cent of combined nitrogen, besides other organic matter, and when properly applied increase the humus in the soil and hence the water-holding power.

To get the best results from peat for these purposes it should be dug and left on the bog for a time to dry out and disintegrate thoroughly. This not only gets rid of the water, but renders the peat more absorbent and in better form to be mixed with the soil. It seems also to make the nitrogenous matters more quickly available for the use of crops to which it is applied.

If dug wet and spread over the land in this condition the peat may dry into hard, tough lumps that for a long time are of no more value to the land than stones or blocks of wood. Aside from this, a ton of wet, freshly dug peat contains only about 225 pounds of usable material, and in this material there is not enough fertilizing substance to justify the labor of digging and hauling it. On the other hand, the dry material, which may be obtained by digging out the peat in the fall and letting it lie on the bog until the next fall, will yield excellent returns, especially if properly composted with coarse manure before being applied to the land.

The composting should be done in the ordinary way, by stacking the peat in thin layers alternating with those of stable refuse to a depth of several feet, and allowing the heap to stand for some months, turning over the whole at least once during the time. If the peat alone is used it should be applied liberally as dry as possible; it may be cheaply spread by a manure spreader. Such applications will improve the productiveness of many kinds of soils.

ABSORBENT AND DISINFECTANT.

The air-dried peat may be used to even better advantage as an absorbent of the valuable nitrogenous liquids of stables and barnyards, which ordinarily are allowed to go to waste. For this purpose the dried peat needs simply to be piled up under cover until used, when it may be spread over the barnyard in layers as needed. If used in the stables, it will not only act as an absorbent of liquids, but, since it checks decomposition and absorbs gases, will be more or less effective as a deodorizer.

Dry, powdery peat may also be used for all the purposes for which peat mull is recommended above, and it is greatly superior, for most of them, to lime, ashes, or the more expensive chemical compounds used for deodorizers and disinfectants. It is nearly an ideal material for use in earth closets and in other receptacles for moist waste organic matter, and has a value far in excess of the cost of gathering and preparing it.

LITTER AND BEDDING FOR STOCK.

Dry peat, if free from sticks and lumps, may be successfully used for bedding for all sorts of live stock, equalling for this purpose the more carefully prepared peat or moss litter, because it possesses all

of the properties of the litter.   When used for bedding the thoroughly dried peat should be packed firmly to the depth of 4 or 5 inches on the floor of the stalls or standing room, at the back of which a retaining cleat should be nailed; if well prepared and kept clean the litter will last without renewal for several months.   It furnishes a standing room and bed which can not be excelled, being spongy, elastic, and absorbent, and keeping down the usual odors of the stable to a marked degree.   Wet peat should not be used for this purpose.

INSULATING MATERIAL.

As dry, fibrous peat is a good nonconductor of heat, it may be used satisfactorily to protect water pipes from freezing.   The peat is probably superior to straw and similar materials commonly used, because it is more durable and, if properly dried, more absorbent, hence would not lose its insulating properties so quickly when laid in a wet place.   The only preparation needed is drying, and manifestly the tough, sponge-like turf, or uppermost layers of moss peat, would be especially desirable, because they afford large air spaces between the fibres, and thus give better protection than more compact material. Peat of this kind should also be good packing in refrigerators and ice-houses and similar structures.

STOCK FOOD.

In Europe peat mull and peat litter prepared from moss and sedge peat have been used as the bases for the preparation of certain kinds of commercial stock foods.   The chief ingredient in these preparations besides the peat is the uncrystallized residue, or molasses, from beet or other sugar factories.   This molasses has a certain food value for fattening stock, but is difficult to feed because of its stickiness and liquid condition, and the peat is added to obviate these difficulties.   Actual analyses, however, by reputable agricultural chemists, show that this material has a twofold use—it is eagerly eaten by the cattle, and thus stimulates them to eat more than they otherwise would of fattening food, and the peat itself adds a small amount of proteid substance to the food; the peat also neutralizes certain bad effects of the molasses, so that larger quantities may be eaten.

Although the weight of evidence gathered at agricultural experiment stations in the United States seems to show that condimental stock foods of the kinds usually sold are of the nature of stimulants, and do not give sufficient returns in actual gains in weight or condition of the animals to justify such use, the testimony as to the value of a mixture of molasses and peat mull as an addition to the ration of horses and other live stock seems conclusive.   Reports of its beneficial

effects have been issued from time to time through a number of years from various European countries and from the army veterinarians of Germany and England.

PACKING MATERIAL.

Air-dried peat can be used to advantage for packing eggs, fruit, and vegetables for storage either in bins, pits, cellars, or other receptacles, or in refrigerating plants.

The nonconducting properties of fibrous peat keep articles packed in it at an even temperature and prevent freezing. In addition peat prevents shrinking due to evaporation and quickly absorbs any water given off. Perishable articles packed in this material are not absolutely protected from decay, because the germs of the microscopic plants that cause decay are generally introduced before packing. Unaffected fruit, however, would not be spoiled by contact with that already inoculated, as is often the case in the usual methods of packing for storage, because peat is sufficiently antiseptic to prevent the growth of rot-producing fungi through it, and the reproducing bodies could not pass from point to point through it, as they do through air spaces.

Large quantities of peat powder or mull are sent annually to the Canary Islands from Europe for use in packing fruit for shipment, and the demand for the material for the purpose is growing. There seems no good reason why the same substance should not be tried in the United States in connection with the shipment for long distances of the more perishable fruits.

PEAT ASHES.

A question often is raised as to the value of peat ashes. In general, it may be said that they are not nearly so valuable as those obtained from wood, as they contain a disproportionately large percentage of silica and very little phosphoric acid or potash. The silica probably comes from fine silty sediments in the water in which the peat was formed, and has practically no value in plant growth although the most abundant constituent of most soils. The small proportion of other mineral constituents in peat ash can probably be attributed to the lack of the remains of woody plants, as the mosses and other herbaceous plants, which are the chief peat formers, do not usually accumulate as much mineral matter in their cell walls as do the shrubs and trees.

Therefore, while at times it may be advisable to burn over the surface of peat beds to remove quickly and cheaply the surface covering of vegetation, it is a great mistake to burn the peat for the sake of getting the ashes, as these are worthless for agricultural purposes in

comparison with the high value of the peat itself for any of the uses that have been mentioned in this bulletin.

It is reported that peat with high ash in certain localities in Florida is burned in specially built furnaces to obtain the ashes for making polishing powders and scouring soaps, the ash containing a large amount of silica in the form of very minute shells of one-celled plants known as diatoms which are so small that they do not produce visible scratches on polished metal, yet so hard that they scour it.

CONCLUSIONS.

Peat land may be cultivated with profit if the right crops are chosen and the peat is sufficiently drained, decomposed, and fertilized. Many of the peat swamps in the northern part of the country are, however, of a type that will scarcely repay cultivation, since the peat is very poorly decomposed and would be a long time in reaching a state in which it could be safely used for most crops.

On the other hand, even poorly decomposed peat may be very profitably used in many ways on farms to increase the fertility of the land, and to add to its productiveness indirectly, by conserving and preserving other more salable articles, or by saving valuable waste matter which could not be kept except by its use.

TABLES OF ANALYSES.

In the following tables all of the analyses of peat samples made by the United States Geological Survey from the beginning of the present investigation to July 1, 1909, are given for convenience of reference and comparison.

COLLECTION OF SAMPLES.

The samples from which these analyses have been made, except the samples from New York, Massachusetts, Michigan, New Hampshire, and North Carolina, were collected chiefly by field agents of the geological surveys of the States in which the peat was obtained, under the supervision of and in cooperation with the United States Geological Survey.

METHODS OF COLLECTION.

In the beginning, samples were collected with augers and placed in galvanized-iron and tin cans, such as were used for sending coal samples by mail to the fuel-testing laboratory of the survey, but it was found that the wet peat from many localities attacked the metal, and, after a relatively short time, etched holes in the sides and bottoms of the containers. This led to the use of glass bottles, after an unsatisfactory test of wooden mailing cases. The bottles finally chosen were ordinary wide-mouthed, 4-ounce size, with tightly fitted corks. Each bottle was rendered mailable by the use of a type of mailing case approved by the postal authorities. The bottles were small because they were used only for wet samples from which the approximate water content of the peat at the time of collection might be determined.

For the calorific and chemical analyses larger samples were always collected at the same time as the bottled samples. The larger samples were placed in stout cotton-cloth bags, about 6 inches wide by 9 inches long, provided with a tape for fastening the top. The samples were generally taken at intervals of 2 feet from the top to the bottom of the deposit, from at least three holes in widely separated parts of the deposit, and portions of each sample were put in a bag and in a bottle as they were collected and were given the same notebook number. Where the lower layers of a deposit showed much

silt samples were sometimes rejected and not included with the material sent for analysis, although this was not the general rule. The bags and the wet samples contained in them before packing were more or less thoroughly dried by exposure to the air, after which they were labeled and sent, with proper identification cards, to the chemical laboratory for analysis. The samples, with the exception of those from Maine,[a] most of which were taken with a ship auger, were collected with the sampling tube already described (pp. 71–72), which has proven very satisfactory for the purpose.

ANALYTICAL METHODS.

The general method used for the proximate analyses of peat samples was that which was adopted by the committee on coal analyses of the American Chemical Society.[b] The Mahler bomb calorimeter was used for determining the calorific or thermal value, 2 grams of peat being taken instead of the 1 gram used in coal analyses. The peat was reduced to the air-dried state by warming it at a temperature of 35° C. (95° F.) in an oven so constructed that a current of warm, dry air passed over the powdered sample until it no longer showed loss of weight on repeated weighing. The time required for this thorough drying was usually from three to five days.[c] The drying was conducted at a temperature used to prevent the loss of volatile combustible matter known to take place when peat is dried at the higher temperatures (100° to 105° C.) often used. Drying in ovens probably gives more uniform results than drying in the open air of the laboratory, because conditions of atmospheric humidity are more definitely controllable in an oven.

MOISTURE.

The difficulties in the way of collecting a peat sample, from any depth below the surface, with exactly the quantity of water that the peat contains at that depth have not all been surmounted, and it is doubtful if any of the samples give as high a percentage of water as they would if perfect collection were possible. The moisture analyses are useful, however, in showing that the water content of the samples collected is uniformly high and often above 90 per cent.

CALORIFIC VALUE.

As previously stated, the calorific value of the peat samples was determined with the Mahler bomb calorimeter. It is stated both in calories and British thermal units on both the air-dried and the

a U. S. Geol. Survey Bull. No. 376, pp. 60–61.

b Jour. Am. Chem. Soc., vol. 21, p. 1116.

c Bull. U. S. Geol. Survey No. 323, 1907, pp. 8–10.

water-free basis, the latter being derived from the former by calculation.   (See pp. 51–52.)

No attempt is made in this report to discuss the analyses, which are published to give those who wish either to learn something of the value of peat for fuel in comparison with other substances now in use or to determine the comparative possibilities of the peat from some particular region or deposit.   To such persons the tables have a distinct value, but, nevertheless, it should be remembered that before a given peat bed is exploited careful tests and analyses should be made of many samples, so that the uncertainty arising from the study of a single analysis can be eliminated.

Analyses of peat by the United States Geological Survey from July 1, 1904, to June 30, 1909.

[F. M. Stanton, Analyst.]

PEAT.

[1=raw peat; 2=moisture free.]

Locality, etc.	Laboratory number.	Condition of sample.	Proximate.				Sulphur.	Ultimate.				Air-drying loss.	Calorific value.		Field number.
			Moisture.	Volatile matter.	Fixed carbon.	Ash.		Hydrogen.	Carbon.	Nitrogen.	Oxygen.		Calories.	B.t.u.	
CONNECTICUT.															
Fairfield County.															
Bethel	6194	1	88.72	6.54	3.13	1.61	0.08					87.90	515	927	39
	6194	2		57.98	27.75	14.27	.71						4,566	8,219	
	6195	1	89.03	6.10	2.65	2.22	.11					88.30	431	866	40
	6195	2		55.61	24.15	20.24	1.00						4,385	7,893	
	6196	1	88.24	4.30	1.34	6.12	.12					87.60	300	540	41
	6196	2		36.56	11.40	52.04	1.02						2,551	4,592	
Brookfield	6182	1	59.01	24.71	12.25	4.03	.30					55.30	2,045	3,681	21
	6182	2		60.28	29.89	9.83	.73						4,969	8,980	
	6183	1	51.43	27.27	11.06	10.24	.53					46.40	2,121	3,818	22
	6183	2		56.15	22.77	21.08	1.09						4,367	7,861	
Danbury	6188	1	93.83	3.79	1.87	.51	.03					93.30	302	544	28
	6188	2		61.43	30.30	8.27	.49						4,896	8,811	
	6189	1	90.31	3.79	1.27	4.63	.08					89.10	294	511	31
	6189	2		39.11	13.11	47.78	.83						2,931	5,276	
New Fairfield	6203	1	9.63	54.65	27.79	7.93	.46					.00	4,367	7,861	48
	6203	2		60.47	30.75	8.78	.51						4,832	8,698	
	6204	1	9.42	46.23	23.87	20.48	.38					.00	3,819	6,874	49
	6204	2		51.04	26.35	22.61	.42						4,216	7,589	
	6205	1	24.90	42.27	18.93	13.90	.84					19.20	3,542	6,376	50
	6205	2		56.28	25.21	18.51	1.12						4,716	8,489	
Ridgefield	6200	1	87.90	7.24	4.02	.84	.04					87.10	600	1,080	45
	6200	2		59.83	33.23	6.94	.33						4,969	8,928	
	6201	1	91.23	5.15	2.98	.64	.03					90.80	421	758	46
	6201	2		58.72	33.98	7.30	.34						4,800	8,640	
	6202	1	82.15	11.52	5.49	.84	.08					81.10	909	1,636	47
	6202	2		64.54	30.75	4.71	.45						5,092	9,166	
Westport	6190	1	9.32	22.47	9.02	59.19	.66					5.00	1,725	3,105	35
	6190	2		24.78	9.95	65.27	.73						1,902	3,424	
	6191	1	12.70	55.61	27.57	4.12	.24					5.80	4,772	8,590	32
	6191	2		68.70	31.58	4.72	.27						5,466	9,829	

Litchfield County.

Kent...............

Washington...............

Woodstock...............

Middlesex County.

Chester...............

Clinton...............

Killingsworth...............

Analyses of peat by the United States Geological Survey from July 1, 1904, to June 30, 1909—Continued.

Locality, etc.	Laboratory number.	Condition of sample.	Proximate.				Sulphur.	Ultimate.				Air-drying loss.	Calorific value.		Field number.
			Moisture.	Volatile matter.	Fixed carbon.	Ash.		Hydrogen.	Carbon.	Nitrogen.	Oxygen.		Calories.	B. t. u.	
CONNECTICUT—continued.															
New Haven County.															
Beaver Marsh (near New Haven)	6155	1	91.20	6.61	1.84	0.35	0.02	10.59	5.00	0.13	83.91	90.10	472	850	129
		2		75.11	20.91	3.96	.23	5.23	56.82	1.48	32.26		5,364	9,655	
	6156	1	93.10	4.14	2.13	.63	.03	10.70	3.69	.15	84.80	92.30	354	637	127
		2		60.00	30.87	9.13	.43	5.22	53.48	2.17	29.57		5,130	9,234	
Cherry Hill Marsh	6157	1	86.98	4.91	2.21	5.90	.14	10.12	4.13	.25	79.46	85.70	406	734	23
		2		37.71	16.98	45.31	1.08	3.53	31.72	1.92	16.44		3,134	5,641	
East Haven	6159	1	87.41	6.66	4.06	1.87	.15					86.00	602	1,084	36
		2	52.90	32.25	14.85	1.19							4,783	8,606	
	6160	1	93.09	5.89	2.98	1.10	.08					89.20	499	908	37
		2		59.43	28.86	11.71	.81						5,035	9,063	
	6161	1	84.69	4.66	1.63	9.02	.28					83.80	351	632	38
		2		30.44	10.64	58.92	1.83						2,288	4,127	
New Haven	6158	1	83.91	4.88	2.76	8.45	.41					83.40	390	702	60
		2		30.33	17.15	52.52	2.55						2,424	4,363	
	6184	1	87.77	4.36	2.54	5.33	.37					87.50	296	533	24
		2		35.65	20.77	43.68	3.08						2,420	4,366	
New London County.															
Franklin	6173	1	92.96	4.29	2.31	.43	.03					92.50	361	650	12
		2		61.11	32.91	5.98	.43						5,142	9,256	
	6174	1	87.82	5.16	1.59	5.43	.08					87.20	370	666	13
		2		42.36	13.06	44.58	.66						3,038	5,468	
	6175	1	87.23	4.13	2.12	6.52	.15					86.40	338	608	14
		2		32.34	16.60	51.06	1.17						2,647	4,765	
Stonington	6180	1	88.55	6.03	8.00	2.42	.09					87.90	523	941	19
		2		52.66	26.20	21.14	.79						4,568	8,222	
	6181	1	87.87	7.42	3.83	.88	.05					87.20	674	1,213	20
		2		61.17	31.68	7.25	.41						5,556	10,001	
Thompson	6162	1	92.25	4.51	2.52	.72	.08					91.60	394	709	2
		2		58.19	32.52	9.29	1.03						5,094	9,151	
	6163	1	85.66	8.52	4.54	1.28	.10					85.00	768	1,382	1
		2		59.41	31.66	8.93	.70						5,356	9,641	
	6164	1	88.64	4.27	2.00	5.00	.11					88.30	336	605	8
		2		37.59	17.60	44.81	.96						2,968	5,324	

Locality	Sample No.	No.													
Windham County.															
Hampton	6176	1	88.52	3.33	1.30	6.95	.06				87.80	245	441	18
		2		29.01	10.45	60.54	.44					2,134	8,841	
	6177	1	91.10	5.19	2.99	.72	.07				90.40	446	803	17
		2		58.31	33.60	8.09	.79					5,011	9,020	
	6178	1	91.50	4.95	2.78	.67	.06				90.90	428	7.70	16
		2		58.93	33.09	7.98	.71					5,095	9,171	
	6179	1	91.02	5.37	3.00	.61	.11				90.30	455	819	15
		2		59.80	33.41	6.79	1.22					5,067	9,121	
FLORIDA.															
Citrus County.															
Inverness, half-mile northeast of (T. 19 S., R. 20 E.)	a 7205	1	89.49								88.60			17.11
	b 7204	1	28.14	43.24	19.73	8.89	.72				21.40	3,725	6,705	17.11
		2		60.17	27.46	12.37	1.00					5,184	9,331	
Clay County.															
Green Grove Springs, about 3 miles southeast of (T. 6 S., R. 26 or 27 E.)	b 7106	1	9.59	6.31	.57	83.43	.08			.12	6.50			5.11
		2		6.96	.74	92.28	1.04			.13				
Dade County.															
Everglades, south edge of	b 7560	1	41.92	6.63	22.38	29.07	.05				40.90	388	698	25.11
		2		11.42	38.53	50.05	.08					668	1,202	
Fort Lauderdale, about 10 miles west of	b 7638	1	91.26	20.10	11.87	6.04	.16				90.40	1,746	3,143	28.11
	b 7637	2	81.99	52.88	31.23	15.89	.42				57.90	4,594	8,200	28.11
Miami, 1½ miles northwest of (sec. 35, T. 53 S., R. 41 E.)	a 7604	1	82.75	11.52	8.69	13.20	.89				64.30	81.90			27.11
	b 7603	1	66.59	34.48	26.01	39.51	2.66							27.11
Miami, 5 miles west of (T. 53 S., R. 41 E.)	a 7602	1	91.63	11.65	7.13	1.91	.13				90.90	1,114	2,005	26.11
	b 7601	1	76.31	56.31	34.46	9.23	.63				77.40	5,384	9,691	26.11
Paradise Key, northwest of	a 7559	1	89.41								88.70			24.11
De Soto County.															
Nocatee, west of	a 7320	1	87.99	51.32	26.18	8.33	.31				87.20	4,459	8,080	21.11
	b 7321	2	14.17	59.79	30.50	9.71	.36				5.90	5,220	9,414	21.11
Duval County.															
Bayard	6028	1	73.10	14.00	8.05	4.85	1.06	9.27	13.37	.53	70.92	69.90	1,283	2,309	169
		2		52.04	29.93	18.03	8.94	4.28	49.70	1.97	22.08		4,770	8,586	
	6027	1	73.66	14.44	8.11	3.89	1.08	9.34	13.84	.51	71.34	67.40	1,295	2,331	171
		2		54.61	30.68	14.71	4.08	4.43	52.34	1.03	22.51		4,898	8,816	
	6030	1	75.29	13.00	7.60	4.11	1.02	9.42	12.70	.48	72.27	70.80	1,195	2,151	175
		2		52.61	30.76	16.63	4.13	4.25	51.40	1.94	21.65		4,836	8,705	
	6029	1	71.14	13.98	7.47	7.41	1.05	8.96	13.21	.48	68.89	63.20	1,248	2,246	173
		2		48.44	25.88	25.68	3.64	3.67	45.77	1.66	19.58		4,324	7,783	

a Bottle sample.   b Sack sample.

Analyses of peat by the United States Geological Survey from July 1, 1904, to June 30, 1909—Continued.

Locality, etc.	Laboratory number.	Condition of sample.	Proximate.				Ultimate.					Air-drying loss.	Calorific value.		Field number.
			Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.		Calories.	B.t.u.	
FLORIDA—continued.															
Duval County—Continued.															
Bayard, 5 miles west of (sec. 28, T. 4 S., R. 27 E.)..	a 7115	1	89.27	27.10	15.86	6.85	1.38			0.94		89.00	2,517	4,531	6.11
	b 7114	1	50.19	54.41	31.84	13.75	2.77			1.89		45.50	5,053	9,095	6.11
	b 7104	2	34.82	36.63	21.11	7.44	2.04			1.09		28.00	3,279	5,902	6.21
		2		56.20	32.39	11.41	3.13			2.59			5,031	9,056	
Hernando County.															
Brooksville, 2 miles southeast of (T. 22 S., R. 19 E.).	a 7262	1	70.04	8.30	4.58	22.37	.05					69.10	659	1,186	20.11
	b 7263	1	64.75	23.55	12.99	63.46	.14					63.30	1,870	3,366	20.11
Istachatta, near (T. 21 S., R. 20 E.)	a 7203	1	84.29	46.19	22.98	12.71	.53					83.00	4,804	8,647	16.11
	b 7202	2	18.12	56.41	28.07	15.52	.65					9.80	5,867	10,561	16.11
Lake County.															
Clermont, 2 miles northwest of (sec. 14, T. 22 S., R. 25 E.)	a 7633	1	95.00	13.77	6.23	.31	.08					94.60			29.11
	b 7632	1	79.69	67.80	30.67	1.53	.39					78.00	1,226	2,207	29.11
	a 7635	2	91.89	11.75	5.72	.41	.05					91.20	6,036	10,865	29.12
	b 7634	2	82.12	65.72	31.99	2.29	.28					80.40	1,048	1,896	29.12
Eldorado, 1 mile northeast of (T. 19 S., R. 25 E.)	a 7254	1	91.74	12.39	5.00	11.26	.17					91.40	5,860	10,548	18.11
	b 7255	1	71.35	43.25	17.45	39.30	.59					70.10	1,011	1,820	18.11
	a 7256	2	90.54	17.98	7.76	1.37	.08					90.00	3,529	6,352	18.12
	b 7257	2	72.89	66.32	28.63	5.05	.29					71.40	1,431	2,576	18.12
Eustis, 3 miles north of (T. 18 S., R. 26 E.)	a 7113	1	75.66	11.11	6.12	77.18	.07			1.75		75.10			3.11
	b 7112	1	5.59	11.77	6.48	81.75	.07			1.85		3.70	5,279	9,502	3.11
Leesburg, just east of (T. 19 S., R. 24 E.)	a 7258	1	93.47	7.60	2.57	5.44	.19			.41		73.10	587	1,057	19.11
	b 7259	1	84.39	48.69	16.46	34.85	1.21			2.62		83.50	3,760	6,768	19.11
	a 7260	2	96.16									94.90			19.12

Locality	No.											
Tavares, 3 miles east of (T. 19 S., R. 26 E.)	b7261	69.89	19.86	7.78	2.47	.11			68.40	1,554	2,797	19.12
	b7310		65.96	26.84	8.20	.37				5,161	9,290	19.21
	b7311	10.68	52.72	29.28	64.80	.54		3.70		4,660	8,388	19.31
	a7109	3.24	59.03	32.77	35.70	.60		.90		5,217	9,391	
	b7108		8.26	5.51	82.99							4.12
			8.54	5.69	85.77							4.12
Tavares, 1½ miles southwest of (T. 19 S., R. 26 E.)	b7111	86.03	16.54	7.54	6.77	.21	.78	86.50	838	1,508	4.11
	b7110	69.15	53.61	24.45	21.94	.68	2.53	67.00	2,716	4,889	4.11
West Apopla, just north of (T. 21 S., R. 26 E.)	a7369	96.13	39.90	20.07	13.82	.55	1.44	95.90	3,700	6,660	23.21
	b7370	26.21	54.07	27.20	18.73	.75	1.95	21.90	5,014	9,025	23.21
	a7367	92.44	16.69	10.20	5.20	.13		91.90	1,563	2,867	23.11
	b7368	67.91	52.01	31.79	16.20	.41		65.50	4,964	8,935	32.11
	a7318	95.52	16.01	10.34	6.75	.09		94.90	1,563	2,813	22.11
	b7319	66.90	48.37	31.24	20.39	.27		64.20	4,722	8,500	22.11
Leon County.		92.24	18.23	7.71	1.57	.11		91.80	1,556	2,801	
		72.49	66.27	28.02	5.71	.40		70.90	5,656	10,181	
Tallahassee, 5 miles west-northwest of (sec. 29, T. 1 N., R. 1 W.)	b7105	54.39	28.78	13.88	1.96	.22	1.06	51.60	2,499	4,444	2.12
			65.29	30.43	4.28	.46	2.30		5,413	9,743	2.12
	b7107	66.23	21.30	9.92	2.55	.08	.88	64.20	1,771	3,188	
			63.07	29.33	7.55	.24	2.61		5,244	9,439	
Manatee County.											
Peaty Prairie, about 2 miles south of (Manatee)	a7691	50.38						55.00		30.11
Osceola County.											
Ashton, 1 mile north of (T. 26 S., R. 31 E.)	a7155	86.80	10.86	7.97	4.69	.09	86.20	1,105	1,989	11.11
	b7154	76.48	46.17	33.89	19.94	.38	75.30	4,068	8,456	11.11
Polk County.											
Auburndale, 2 miles west of	a7199	94.32	47.91	31.06	6.73	.35	93.90	4,561	8,210	14.11
	b7198	14.30	55.90	36.25	7.85	.41	5.80	5,322	9,580	14.11
Bartow Junction, and Auburndale, half way between (T. 28 S., R. 25 or 26 E.)	a7167	95.51	34.43	19.66	2.36	.17	95.20	3,269	5,894	13.11
	b7166	43.55	60.99	34.83	4.18	.30	38.90	5,791	10,424	13.11
	a7169	92.68	25.98	14.52	4.85	.18	92.10	2,359	4,246	
	b7168	54.65	57.29	32.02	10.69	.40	50.60	5,202	9,364	

a Bottle sample.

b Sack sample.

Analyses of peat by the United States Geological Survey from July 1, 1904, to June 30, 1909—Continued.

Locality, etc.	Laboratory number.	Condition of sample.												Field number
FLORIDA—continued.														
Polk County—Continued.														
Florence Villa, half mile north of (T. 28 S., R. R. 26 E.)	a 7165	1	63.19						0.11	44.20	15.41	40.74	4,103	12.11
	b 7164	2							.25	36.99	24.85	38.28	3,534 6,361	12.11
Lakeland, 2 miles east of (T 28 S., R. 24 E.)	a 7201	1	94.40						.34	2.84	28.92	55.07	6,072 9,130	15.11
	b 7200	2	13.37						.39	3.05	33.38	68.57	5,855 10,530	15.11
Putnam County.														
Palatka, 1 mile south of (T. 10 S., R. 27 E.)	a 7151	1	90.85						.49	8.18	6.32	9.72	923 1,061	8.11
	b 7150	2	80.78						2.06	16.55	33.66	50.57	4,802 8,644	8.11
Santa Rosa County.	a 7158	1	88.94						.21	1.99	8.55	11.79	1,100 2,104	8.21
	b 7152	2	77 67						.94	8.91	38.29	52.80	5,235 9,425	8.21
Milton, near (T. 1 N., R. 28 W)	a 7021	1	71.68						.85	33.38	2.85	6.63	604 1,067	7.11
	b 7022	2	68.14						.84	79.74	6.81	14.45	1,443 2,057	7.11
Sumter County.	a 7028	1	83.50						.66	21.05	2.70	6.35	601 902	7.12
	b 7024	2	68.99						2.12	67.66	11.90	20.44	1,619 2,596	7.12
Lake Panasoffkee, south end of	a 7697	1	86.30											32.11
	a 7698	1	92.17											32.12
	a 7699	1	93.68											21.11
IOWA.														
Decatur County.														
De Kalb, at	5216	1	12.33						1.46	45.99	12.34	28.34		
		2							1.07	53.60	14.07	33.83		

MAINE.

Location	Sample No.																							
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	28
Androscoggin County.																					
Greene, near	5895	1	86.52	7.55	4.22	1.71	.08			0.24	85.00		655	1,179
		2	56.01	31.80	12.60	.59				1.78			4,859	8,746
Lewiston, 2 miles east of ((Garcelon bog)	5893	1	82.71			1.16	.08			.20	80.80		5,892	1,605
		2					.12			1.16			5,159	9,286
Lewiston, 2 miles east of	5897	1	86.98	7.84	4.40	.78	.02			.13	84.20		682	1,228
		2		60.22	33.79	5.99	.15			1.00			5,238	9,428
Lewiston, 2 miles east of	5894	1	85.91	8.43	4.37	1.29	.07			.23	84.60		715	1,287
		2	59.83	31.01	9.16	.50				1.63			5,057	9,136
Lewiston, 2 miles east of (machine peat)	5865	1	66.39			1.55	.17			.46	60.40		1,127	2,029
		2				4.43	.49			1.33			3,256	5,951
Lewiston, 4 miles east of (bog south of No Name Pond)	5864	1	87.55			.67	.02			.14	86.10		610	1,098
		2		5.83	2.95	5.38	.16			1.12			4,900	8,820
Lewiston, 4 miles east of	5866	1	88.67	51.46	26.03	2.55	.02			.13	87.60		460	828
		2					.18			1.15			4,060	7,808
	5896	1	85.49	8.01	3.99	2.51	.06			.20	84.40		634	1,141
		2		55.20	27.50	17.90	.34			1.38			4,399	7,864
Aroostook County.																					
Crystal, 2 miles southwest of	5912	1	85.02			1.41	.04			.23	83.61		783	1,373
		2				9.41	.27			1.54			5,063	9,167
Houlton, 1 mile southwest of	5913	1	87.47			.75	.02			.16	86.30		678	1,220
		2				5.99	.16			1.28			5,411	9,740
Sherman, near	5914	1	86.18	8.27	3.98	1.57	.10			.28	82.80		719	1,294
		2		59.84	28.80	11.38	.72			2.03			5,203	9,385
Cumberland County.																					
Cape Elizabeth, near	5861	1	85.87	8.12	4.25	1.76	.14			.26	84.00		701	1,262
		2	57.47	30.07	12.46	.99				1.84			4,961	8,930
	5895	1	84.44	8.93	4.95	1.68	.17				82.00			
		2	57.89	31.81	10.80									
Cumberland Mills, 5¼ miles north of	5844	1	91.00	5.41	2.60	.99	.01			.07	89.20		419	754
		2	60.11	28.89	11.00	.11				.78			4,656	8,381
	5836	1	89.59	6.42	3.27	.72	.01			.08	88.30		521	938
		2	61.67	31.41	6.92	.10				.77			5,005	9,009
Hancock County.																					
Bucksport	5888	1	86.80			.73	.02				86.00		672	1,210
		2				5.21	.14						4,800	8,640
Nicolin station, one-third mile north of	5837	1	86.13	8.13	4.84	.90	.02			.13	84.40		711	1,280
		2	58.63	34.86	6.49	.14				.94			5,126	9,227
Kennebec County.																					
Augusta	5881	1	80.64			6.38	.16			.31	78.60		756	1,361
		2		6.34		82.96	.83			1.60			3,905	7,029
Benton Falls, 2¼ miles southeast of	5885	1	77.11	9.93		6.62	.17			.45	74.90		911	1,640
		2	43.38	27.70	28.92	.74				1.97			3,980	7,164

a Bottle sample.   b Sack sample.

Analyses of peat by the United States Geological Survey from July 1, 1904, to June 30, 1909—Continued.

Locality, etc.	Laboratory number.	Condition of sample.	Field number.
MAINE—continued.			
Kennebec County—Continued.			
Oakland, 8 miles north of (Martin Stream bog)	5915	1, 2	20
West Sidney, near (Great Sidney bog)	5976	1	21
West Sidney, west of (Great Sidney bog)	5979	2, 1	22
West Sidney	5960	2, 1	23
	5961	2, 1	24
	5962	2, 1	25
	5963	2, 1	26
	5964	1, 2	27
Winslow	5965	1, 2	19
	5966	1, 2	28
Knox County.			
Rockland, 2½ miles northwest of	5935	1, 2	30
	5940	1, 2	31
Oxford County.			
Hartford, north of	5937	1, 2	32
Norway, 3½ miles north of	5939	1, 2	33
Penobscot County.			
Albion, 1½ miles north of	5938	1, 2	34

	Location	No.														
41	Bangor, 10 miles north of	5893	1	86.95			86.00		.28		.04	1.10			670	1,206
42		5890	2	87.05			86.40		1.99		.31	8.43			5,134	9,241
36	Etna, 1 mile west of	5891	1	84.68			83.60		2.01		.08	2.39			585	1,053
			2								.62	18.46			4,517	8,131
37	Hermon Center, west of	5902	1	86.48			85.60		.35		.10	1.33			779	1,402
			2						2.23		.65	8.68			5,085	9,153
38	Hermon Pond, southwest of	5892	1	88.23			87.00		.29		.07	1.50			678	1,220
			2						2.14		.52	11.09			5,015	9,027
39		5916	1	89.01			86.80		.25		.06	1.15			587	1,057
			2						2.12		.51	9.77			4,987	8,977
40	Newport, three-fourths mile east of	5899	1	85.59	6.93		84.80		.23		.04	.63	3.43	6.93	598	1,058
			2		63.06				2.09		.36	5.73	31.21	63.06	5,350	9,630
35	Spragues, near	5841	1	88.34			85.00		.17		.03	1.09			736	1,325
			2						1.18		.14	7.55			5,108	9,194
	Somerset County.										.02	.84			507	1,075
43	Oakland, 4 miles north of	5884	1	83.64			82.20		1.20		.17	7.20			9,120
			2						.21		.03	.90			872	1,570
44		5880	1	83.66			82.30		1.28		.18	4.89			5,330	9,594
			2						.26		.11	4.09			667	1,201
45	Pittsfield, 1 mile southeast of	5904	1	90.88	6.41	10.58	90.20	84.30	1.59	4.41	.67	25.03	2.10	6.41	4,082	7,348
			2		70.29	5.26		38.50	.09	48.36	.01	.61	23.02	70.29	412	742
46		5896	1	89.85			89.10		.99		.11	6.69			4,518	8,132
			2						.10		.02	.64			514	925
47	Smithfield	5887	1	86.06			85.20		.99		.20	6.31			5,064	9,115
			2						.19		.04	.62			813	1,463
	Washington County.								1.36		.29	4.45			5,832	10,498
58	Ayers Junction, half mile east of	5633	1	85.22	8.96		83.80				.07	1.20	4.72	8.96	803	1,444
			2		59.95				.11		.47	8.12	31.93	59.95	5,433	9,779
56	Ayers Junction, 1½ miles southwest of	5904	1	87.61			86.40		.99		.02	.66			657	1,183
			2						.10		.16	5.36			5,303	9,545
57		5903	1	88.21			87.10		.85		.02	.66			612	1,102
			2						.07		.17	5.60			5,191	9,344
48	Cherryfield, 3½ miles northeast of	5909	1	91.27			90.50		.80		.01	.84			398	716
			2						.05		.11	9.62			4,559	8,206
49	East Machias, 7 miles north of	5906	1	91.96			91.00		.60		.01	.45			403	725
			2								.12	5.42			4,850	8,730
59	Falls Point, 1 mile northwest of	5976	1	89.76	7.10		89.00				.02	.20	2.94	7.10	
			2		69.34						.20	1.95	28.71	69.34	
60		5977	1	91.51	5.50		90.90				.02	.36	2.63	5.50	520	936
			2		64.78						.24	4.24	30.98	64.78	5,221	9,398
51	Forest, northwest of	5908	1	90.04			89.10		.12		.02	.57			448	806
			2						1.20		.20	5.72			4,934	8,881
54	Jonesboro	5911	1	90.92			90.00		.07		.08	.48			331	596
			2						.77		.22	5.29			4,642	8,356
53	Shoppers Point, 1½ miles northeast of	5907	1	92.87			92.30		.05		.02	.55			519	934
			2						.70		.28	7.71			5,000	9,000
50	Southern Inlet, east of	5905	1	89.62			88.70		.08		.02	.43			
			2						.77		.19	4.14			

Analyses of peat by the United States Geological Survey from July 1, 1904, to June 30, 1909—Continued.

Locality, etc.	Laboratory number.	Condition of sample.	Proximate.				Ultimate.					Air-drying loss.	Calorific value.		Field number.
			Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.		Calories.	B.t.u.	
MAINE—continued.															
Washington County—Continued.															
South Lubec, three-fourths mile southeast of......	5875	1	88.41	7.72	3.43	0.44	0.03	10.44	6.06	0.09	82.94	87.50	574	1,033	55
		2		66.61	29.59	3.80	.26	5.35	52.29	.78	37.52		4,953	8,915	
Vanceboro, 2 miles west of......	5842	1				.68	.01			.08		89.80	400	720	63
		2	91.55			8.05	.12			.71			4,734	8,521	
	5843	1	89.65	6.33	3.15	.87	.02			.13		87.60	536	965	64
		2		61.16	30.43	8.41	.19			1.26			5,179	9,322	
Whitneyville, 2 miles west of......	5910	1				.52	.02			.07		89.20	478	860	52
		2	90.28			5.35	.21			.72			4,918	8,852	
York County.															
Kittery (Cutts Island, salt marsh)......	a6552	1	88.94	33.18	19.89	38.76	1.69					86.30	2,576	4,637	150
Kittery (Cutts Island, salt marsh)......	b6553	2	8.17	36.13	21.66	42.21	1.84					3.60	2,805	5,049	150
Kittery (Cutts Island, salt marsh)......	a6556	1	80.13	27.17	11.20	52.57	1.99					79.00	1,836	3,305	152
Kittery (Cutts Island, salt marsh)......	b6557	2	9.06	29.88	12.31	57.81	2.19					5.10	2,019	3,634	152
Kittery Point (salt marsh)......	a6554	1	87.51	49.06	25.40	12.04	1.94					86.30	4,066	7,319	151
Kittery Point (salt marsh)......	b6555	2	13.50	56.72	29.36	13.92	2.24					5.10	4,701	8,462	151
Rosemary Junction (salt marsh)......	a6565	1	86.55	41.20	22.00	22.54	1.32					85.30	3,541	6,374	157
Rosemary Junction (Rosemary swamp)......	b6566	1	14.26	48.06	25.66	26.29	1.54					7.30	4,130	7,434	157
Rosemary Junction (Rosemary swamp)......	a6567	1	88.11	32.12	15.12	41.84	1.30					87.20	2,632	4,788	158
Rosemary Junction (Rosemary swamp)......	b6568	2	10.92	36.06	16.97	46.97	1.46					5.00	2,955	5,819	158
MASSACHUSETTS.															
Essex County.															
Lynnfield......	a6611	1	90.18	46.34	23.38	9.11	.61					89.50	4,004	7,207	169
	b6612	2	21.17	58.79	29.65	11.56	.77					15.40	5,079	9,142	169
Hampshire County.															
Norwood (Neponset Meadows bog)......	a6615	1	89.37									88.40			172

Sample No.	Locality	Ref. No.
b 6616	Norwood	172
b 6623	Norwood (machine peat)	173
	Middlesex County.	
a 6613	East Lexington	170
b 6614	East Lexington	170
b 6622	East Lexington (machine peat)	171
	MICHIGAN.	
	Allegan County.	
a 6725	Shelbyville, 4 miles southeast of (Gunn marsh)	608
b 6724	Shelbyville, 4 miles southeast of	608
	Kalamazoo County.	
a 6721	Kalamazoo, near (Elk marsh)	605
b 6720	Kalamazoo, near (Elk marsh)	605
b 6722	Kalamazoo, near (Elk marsh, cut peat)	606
b 6723	Kalamazoo, near (machine peat)	607
	Livingston County.	
a 6719	Hamburg, 1 mile west of	604
a 6718	Hamburg, 1 mile west of	604
	Monroe County.	
a 6300	Lambertville, 12 miles north of Toledo, Ohio	601
b 6299	Lambertville, 12 miles north of Toledo, Ohio	601
	NEW HAMPSHIRE.	
	Rockingham County.	
a 6575	Freemont	163
b 6576	Freemont	163
6569	Greenland (Great Bay, salt-marsh peat)	159
a 6570	Greenland (Great Swamp)	160
b 6571	Greenland (Great Swamp)	160
a 6561	Rye (salt-marsh peat)	159
b 6562	Rye (salt-marsh peat)	159

a Bottle sample.   b Sack sample.

Analyses of peat by the United States Geological Survey from July 1, 1904, to June 30, 1909—Continued.

Locality, etc.	Laboratory number.	Condition of sample.	Proximate.					Ultimate.					Air-drying loss.	Calorific value.		Field number.
			Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.		Calories.	B.t.u.	
NEW HAMPSHIRE—continued.																
Strafford County.																
Dover	a6573	1	85.49	52.67	27.02	4.51	0.46						84.50	4,552	8,194	162
Dover	b6574	1	15.80	56.55	32.09	5.36	.55						9.30	5,406	9,731	162
Farmington, 4 miles north of (Ely River bog)	a6577	1	89.76	42.90	20.28	23.14	.59						89.10	3,647	6,565	164
Farmington, 4 miles north of	b6578	2	13.68	49.70	23.49	26.81	.68						8.10	4,225	7,605	164
New Durham (Merrymeeting bog)	a6579	1	88.15	48.30	22.25	16.63	.83						87.30	4,097	7,375	165
New Durham (Merry meeting bog)	b6580	2	12.82	55.40	25.52	19.08	.94						7.20	4,700	8,460	165
Rochester	b6572	1	11.64	58.97	25.33	4.06	.22						7.20	5,046	9,083	161
		2		66.74	28.67	4.59	.25							5,711	10,280	
NEW YORK.																
Essex County.																
Bloomingdale	a6430	1	89.06	57.14	28.07	2.78	.23						88.30	4,931	8,876	40
	b6429	2	12.01	64.94	31.90	3.16	.26						8.20	5,604	10,067	40
Franklin County.																
Mountain View	a6428	1	88.40	59.71	25.80	3.48	.13	6.50	50.88	1.32	37.69	87.60	5,098	9,172	39
	b6427	1	11.01	67.10	28.99	3.91	.15	5.93	57.17	1.48	31.36	7.80	5,726	10,307	39
Saranac Lake	b6431	2	11.74	43.84	13.23	31.19	.84						8.60	3,244	5,839	41
		2		49.67	14.99	35.34	.95							3,675	6,615	
Livingston County.																
South Lima	a6663	1	69.20	26.14	11.17	5.99	.64	8.33	21.03	1.10	62.91	66.30	1,992	3,586	55
	b6664	1	56.70	50.37	25.80	13.83	1.48	4.69	48.57	2.54	28.89	53.40	4,600	8,280	55
Madison County.																
Canastota	b6639	1	24.70	45.51	20.63	9.16	.42	6.22	36.13	1.87	46.20	17.80	3,274	5,893	52
		2		60.44	27.40	12.16	.56	4.62	47.98	2.48	32.20		4,343	7,826	52
Onondaga County.																
Cicero	a6399	1	89.70	54.80	23.21	7.42	.25						89.20	4,209	7,576	35
	b6398	1	14.57	64.14	27.17	8.69	.29						9.90	4,927	8,869	35

Locality	Lab. No.	Sample												No.
Elbridge, 2 miles east of Big Swamp bog	b 7080	1	9.32	37.00	18.93	34.85	.97				4.40		3,043	5,466	2
		2		40.80	20.77	38.43	1.07						3,361	6,050	
Half Way	b 7081	1	9.88	36.46	17.17	36.39	1.60				5.00		2,976	5,357	1
		2		40.50	19.07	40.43	1.78						3,306	5,951	
Memphis	b 7078	1	7.39	24.31	9.69	58.61	1.26				3.10		1,909	3,256	3
		2		26.25	10.46	63.29	1.36						1,963	3,515	
Orleans County.															
Oak Orchard	a 6397	1	60.87	42.48	9.38	22.74	.45	5.66	25.28	1.96	58.90		2,288	4,118	34
	b 6396	2	25.40	56.94	12.58	30.48	.60	3.81	33.86	2.63	20.20	43.93	3,067	5,521	34
	a 6405	1	86.98	49.75	21.75	11.98	1.49				88.20		3,784	6,811	38
	b 6404	2	16.52	58.60	26.05	14.35	1.78				10.20		4,533	8,159	38
	a 6403	1	87.20	49.37	20.44	14.60	1.64				86.50		3,834	6,901	37
	b 6402	2	15.59	58.49	24.21	17.30	1.94				10.10		4,542	8,176	37
Oswego County.															
Fulton, 7 miles east of	a 6636	1	93.98	29.15	12.44	3.75	.17				93.50		2,280	4,104	51
	b 6637	2	54.66	64.29	27.44	8.27	.37				51.60		5,029	9,052	
Hastings, at, 4 miles west of Central Square	b 7079	1	7.03	31.60	17.46	43.91	.74				2.80		2,557	4,693	4
		2		33.99	18.78	47.23	.80						2,750	4,950	
Palermo	a 6634	1	90.44	16.29	7.47	2.49	.16				89.40		1,237	2,227	50
	b 6635	2	74.78	60.63	29.62	9.75	.63				72.40		4,905	8,829	50
West Monroe	a 6401	1	92.27	44.55	24.55	12.45	.75	5.95	41.63	1.71	91.90	37.51	3,994	7,189	36
	b 6400	2	18.45	54.63	30.10	15.27	.92	4.78	51.05	2.10	12.10	25.88	4,897	8,815	36
St. Lawrence County.															
Ogdensburg, near Black Lake bog (machine peat)	a 6393	1	11.54	49.43	21.59	16.98	.91				6.20		3,897	7,015	31
	b 6392	2	12.00	56.17	24.53	19.30	1.03				5.00		4,428	7,971	31
Ogdensburg, near Black Lake bog (peat from barge)	b 6436	1	16.81	46.39	21.67	15.13	.90				8.90		3,907	6,853	30
		2		55.77	26.04	18.19	1.08						4,576	8,237	
Ogdensburg, near Black Lake bog (machine peat)	b 6394	1	16.67	45.81	21.47	16.05	.82				8.10		3,727	6,709	32
		2		54.97	25.77	19.26	.98						4,472	8,050	
Ogdensburg, near Black Lake bog (briquetted peat)	b 6395	1	16.37	47.44	20.40	15.79	1.06				9.10		3,811	6,860	33
		2		56.73	24.39	18.88	1.27						4,557	8,203	
Arkport	a 7083	1	87.45	43.33	20.50	22.99	1.38				86.60		3,493	6,287	6
	b 7082	2	13.18	49.91	23.61	26.48	1.59				7.00		4,023	7,241	6
Steuben County.															
NORTH CAROLINA.															
Pasquotank County.															
Elizabeth City	b 5585	1	95.12	7.72	4.29	2.87	.33	10.06	7.06	.25	83.20	79.43	682	1,228	6
		2		51.88	28.83	19.29	2.22	4.03	47.45	1.68		25.83	4,583	8,249	

a Bottle sample.   b Sack sample.

Analyses of peat by the United States Geological Survey from July 1, 1904, to June 30, 1909—Continued.

Locality, etc.	Laboratory number.	Condition of sample.	Proximate. Moisture.	Proximate. Volatile matter.	Proximate. Fixed carbon.	Proximate. Ash.	Proximate. Sulphur.	Ultimate. Hydrogen.	Ultimate. Carbon.	Ultimate. Nitrogen.	Ultimate. Oxygen.	Air-drying loss.	Calorific value. Calories.	Calorific value. B.t.u.	Field number.
WISCONSIN.															
Ashland County.															
Glidden	a 6424	1	92.32									91.80			323
	b 6423	1	13.20	53.08	23.45	10.27	0.20					9.00	4,410	7,938	323
		2		61.15	27.02	11.83	.23						5,081	9,146	
Chippewa County.															
New Auburn	a 6389	1	92.87									92.50			315
	b 6384	1	12.18	60.93	24.23	12.66	.19					4.90	4,344	7,819	
		2		57.99	27.59	14.42	.22						4,947	8,905	
Dane County.															
Madison (University Bay marsh)	a 6292	1	85.39									84.30			302
	b 6278	1	71.33	16.01	6.75	5.91	.12					68.50	1,215	2,187	302
		2		55.84	23.55	20.61	.42						4,288	7,628	
Madison	a 6346	1	81.92									80.10			310
	b 6345	1	76.09	11.33	4.14	8.44	.08					72.90	828	1,490	310
		2		47.39	17.31	35.30	.33						3,463	6,233	
	a 6348	1	83.57									82.20			311
	b 6347	1	78.30	11.92	5.99	3.79	.05					75.80	1,066	1,919	311
		2		54.93	27.60	17.47	.23						4,912	8,842	
	a 6350	1	63.07	8.75	2.18	26.00	.07					61.30	535	963	312
		2		23.69	5.91	70.40	.19						1,449	2,608	
	b 6349	1	49.03	14.60	3.49	32.88	.13					45.30	907	1,633	312
		2		28.64	6.85	64.51	.26						1,770	3,202	
Mendota, 1 mile northwest of	a 6281	1	83.55	18.16	6.89	9.88	.16					82.00	1,337	2,407	301
	b 6277	1	65.07	51.99	19.73	28.28	.45					61.50	3,828	6,890	301
Door County.															
Sturgeon Bay	a 6472	1	92.15	51.28	15.18	18.80	.72					91.40	3,741	6,734	327
	b 6471	1	14.74	60.15	17.80	22.06	.84					6.80	4,388	7,898	327
Fond du Lac County.															
Fond du Lac, 7 miles west of (remains of peat briquets)	b 6279	1	15.89	44.96	23.49	15.66	.74					6.60	3,875	6,975	303A
		2		53.45	27.93	18.62	.88						4,607	8,293	

Locality	Lab No.	No.	A	B	C	D	E	F	G	H	I	J	K	L	ID
Fond du Lac, 7 miles west of	a 6288	1	86.16	13.37	5.70	3.99	.17	9.57	10.87	.68	74.72	85.00	1,044	1,879	303B
	b 6280	1	76.94	57.98	24.72	17.30	.74	4.42	47.14	2.95	27.45	73.80	4,527	8,140	303B
Iron County.		2													
Powell	a 6422	1	88.29	46.99	22.44	13.36	.79					87.50	3,704	6,757	322
	b 6421	1	17.21	56.76	27.10	16.14	.96					11.40	4,584	8,161	322
Kewaunee County.		2													
Algoma	a 6465	1	70.07	37.17	14.66	37.42	.26					67.60	2,919	5,254	326
	b 6464	1	10.75	41.65	16.42	41.93	.28					3.50	3,270	5,886	326
Kewaunee	a 6463	1	87.85	50.65	22.16	12.68	.44					86.70	3,803	6,845	325
	b 6462	2	14.51	59.25	25.92	14.83	.51					6.10	4,448	8,006	325
Langlade County.		1													
Antigo	a 6527	2	80.24	9.21	4.17	6.38	.13					78.60	698	1,256	332
				46.61	21.10	32.29	.66						3,532	6,358	
Lincoln County.		1													
Heafford Junction	a 6412	1	94.02	48.21	18.38	19.65	.21					93.70	3,857	6,943	318
	b 6411	2	13.76	55.90	21.31	22.79	.24					10.10	4,473	8,051	318
Manitowoc County.		1													
Kiel, 7 miles northeast of	a 6293	1	84.82	40.45	13.37	23.34	1.26					83.60	2,837	5,107	306
	b 6292	2	22.84	52.42	17.33	30.25	1.63					16.40	3,677	6,619	306
	b 6294	1	33.28	37.45	15.34	13.93	1.08					28.40	2,886	5,195	307
		2		56.13	22.99	20.88	1.62						4,326	7,787	
	a 6296	1	88.11	42.22	16.60	14.58	.65					86.90	3,148	5,666	308
	b 6295	1	26.60	57.52	22.62	19.86	.89					20.40	4,289	7,720	308
Marinette County.		2													
Pembine	a 6508	1	83.97	47.16	21.58	15.84	1.41	5.51	39.62	1.45	36.17	82.80	3,682	6,628	329
	b 6507	1	15.42	55.75	25.52	18.73	1.67	4.49	46.84	1.71	26.56	6.80	4,353	7,835	329
Peshtigo	a 6516	2	76.36	10.78	4.66	8.20	.16					75.10	832	1,498	328
		1		45.60	19.71	34.69	.68						3,519	6,334	
Oconto County.		1													
Cameron	a 6390	2	91.19	54.49	24.29	7.19	.25					90.50	4,392	7,906	316
	b 6385	1	14.03	63.38	28.26	8.36	.29					9.30	5,109	9,196	316
Mountain	a 6526	1	87.57	47.43	22.19	10.56	.60					86.60	3,480	6,264	333
	b 6525	2	19.82	59.15	27.68	13.17	.75					12.90	4,340	7,812	333

a Bottle sample.   *b* Sack sample.

Analyses of peat by the United States Geological Survey from July 1, 1904, to June 30, 1909—Continued.

Locality, etc.	Laboratory number.	Condition of sample.									Calorific value.		Field number.
											Calories.	B. t. u.	
WISCONSIN—continued.													
Oneida County.													
Gagen	a 6510	1	87.18	53.09	23.44	8.05	0.19				86.40	4,413	7,943	330
	b 6509	1	15.42	62.77	27.71	9.53	.22			10.30	5,217	9,391	330
Price County.													
Parthala	a 6426	1	73.73	30.39	17.49	31.51	.28			71.10	3,215	5,787	324
	b 6425	1	11.67	44.69	19.74	35.67	.82			8.00	3,640	6,553	324
		2												
Rusk County.													
Ladysmith	a 6591	1	89.11	49.70	19.34	19.63	.21			89.50	3,917	7,051	317
	b 6590	1	11.36	55.16	21.53	22.02	.25			7.80	4,418	7,952	317
Sawyer County.													
Hayward	a 6587	1	91.41	46.20	22.61	12.70	.24			90.90	3,977	7,159	313
	b 6583	1	15.29	55.64	27.92	15.54	.29			9.00	4,967	8,761	313
		2						41.67	1.57	5.83	37.94			
	a 6588	1	91.46	46.35	17.60	18.71	.35	51.00	1.92	4.71	26.54	91.10	3,662	6,574	314
	b 6583	1	18.14	55.40	21.74	22.86	.48				11.30	4,460	8,028	314
		2												
Sheboygan County.													
Kley, 6 miles southwest of	a 6596	1	91.06	50.85	20.13	9.10	.55			90.30	3,969	6,964	309
	b 6597	1	20.43	63.28	25.28	11.44	.69			12.30	4,963	8,763	309
Vilas County.													
Eagle River	a 6412	1	86.43	58.40	21.87	9.40	.28			85.70	4,375	7,675	331
	b 6411	1	15.88	63.44	26.39	11.17	.27			11.20	5,198	9,356	331
		2												
Lac du Flambeau	a 6420	1	84.52	47.74	20.57	18.70	.14			83.70	4,171	7,506	321
	a 6419	1	13.19	54.99	23.47	21.54	.16			10.80	4,806	8,649	321
		2												
Minocqua	a 6414	1	83.99	42.52	17.67	19.85	.24			83.20	3,517	6,331	319
	b 6413	1	19.96	53.12	22.05	24.90	.30			14.10	4,394	7,900	319
		2												

Location	Sample													No.
Waupaca County.														
	a 6416	1	92.83	47.14	17.09	22.41	.45				92.50	3,660	6,570	320
	b 6415	1	13.86	54.41	19.72	25.87	.52				9.20	4,218	7,583	320
		2												
Waupaca, ½ mile north of	a 6289	1	86.59	43.71	18.99	12.40	.30				86.00	3,409	6,136	304
	b 6288	1	25.00	53.29	25.18	16.53	.40				19.40	4,545	8,181	304
		2												
Waupaca, 3 miles northwest of	a 6291	1	95.29	48.12	11.86	21.26	.57	6.09	82.71	2.30	94.90	3,399	6,064	305
	b 6290	1	18.76	59.23	14.60	26.17	.70	4.94	40.26	2.83	13.00	4,147	7,465	305
		2							87.07 25.10					

a Bottle sample.   b Sack sample.

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BULLETIN 1. The volatile matter of coal, by H. C. Porter and F. K. Ovitz. 1910. 56 pp. 1 pl.

BULLETIN 2. North Dakota lignite as a fuel for power-plant boilers, by D. T. Randall and Henry Kreisinger. 1910. 42 pp., 1 pl.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp.

BULLETIN 4. Features of producer-gas power-plant development in Europe, by R. H. Fernald. 1910. 27 pp., 4 pls.

BULLETIN 5. Washing and coking tests of coal at Denver, Colo., July 1, 1908, to June 30, 1909, by A. W. Belden, G. R. Delamater, J. W. Groves, and K. M. Way. 1910. 62 pp.

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GAS AND DUST GALLERY NO. 1, PITTSBURG TESTING STATION.

Bulletin 17

DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

JOSEPH A. HOLMES, Director

A PRIMER ON EXPLOSIVES
FOR COAL MINERS

BY

CHARLES E. MUNROE

AND

CLARENCE HALL

————

[Reprint of United States Geological Survey Bulletin 423]

WASHINGTON

GOVERNMENT PRINTING OFFICE

1911

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NOTE.

This bulletin is issued and distributed in the hope that it may lessen the accidents caused by the improper use of explosives in mining operations. The Bureau of Mines will be glad to receive any suggestions as to additions or other changes which, in the opinion of readers, would increase the usefulness of this primer in accomplishing this purpose.

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INTRODUCTION.

By J. A. HOLMES.

Of the common causes of the larger mine accidents, such as falls of roof and coal, gas and dust explosions, mine fires, and the misuse of explosives, all of which are often closely related, each must be studied and fought in a manner peculiar to itself. The last mentioned, the misuse of black powder and other explosives, is sometimes considered the least important of these causes of mine accidents; but its importance is much greater than the statistics indicate, for the reason that the misuse of explosives is the true cause of many of the fatal mine fires, gas or dust explosions, and falls of roof that are credited to other causes.

Both the quantity of explosives used and the number of purposes to which they are applied are increasing. They are now made at about 150 plants, in different parts of the United States, and the product of a single year is estimated at nearly 500,000,000 pounds. Nothing in all this material is a safe or "safety" explosive when in the hands of a careless or ignorant person; and this is true whether considered in connection with the shipment or the use of these explosives. In addition to the large losses of life and property resulting from an improper use of explosives in mining, the recent statistics of the railway bureau for the safe transportation of explosives have shown more than 400 persons killed or injured and over $3,000,000 worth of property destroyed by explosives in transit by rail. The fact that three years of cooperative effort under the wise supervision of this bureau has reduced these losses to almost nothing encourages the hope that similar cooperative effort may likewise greatly lessen losses of life and property from the use of explosives in mining.

The additions to the large death roll of our mines make a recurring appeal to the public for fair treatment of the coal-mining industry, and to the miner and the manager that they join in every possible effort for greater safety. It may never be possible under conditions such as exist to-day to prevent mine accidents entirely. Little can be accomplished in that direction by either the operators or the miners working alone, but experience in all countries shows that

through the hearty determined cooperation of both the accidents
may be greatly reduced.   This will require wise laws and regulations
based on fact and experience, and the strictest possible discipline.

The accidents resulting from the improper use of explosives in
mining can be most certainly prevented (1) through the use of the
best and safest explosives; (2) through the handling and firing of
these explosives in the safest manner by carefully selected and
trained men; and (3) through the strict and competent oversight of
these men.

This little book on explosives is published in the hope that it
may aid in preventing such accidents.   The aim has been to tell
what explosives are and how they should be handled, with a view
to greater safety; and to do this in language free of unnecessary
technicalities.   It has been prepared by Charles E. Munroe, con-
sulting chemist, and Clarence Hall, explosives engineer of the Bureau
of Mines.   It has been revised in the light of suggestions made by
the mining engineers associated with the bureau, by several mine
managers, by experts associated with the manufacture of explosives,
and by Col. B. W. Dunn, chief of the bureau for the safe transporta-
tion of explosives, who has also kindly added a brief chapter on
the transportation of explosives.

Much of the information in this primer has been obtained from
experiments conducted by the technologic branch of the United
States Geological Survey at the mining experiment station at Pitts-
burg, Pa.   This station, which is now part of the Bureau of Mines,
was authorized for conducting investigations as to the "causes of
mine explosions."   These investigations have shown the recent
development of a new type of short-flame explosives, which can be
used with greater safety than black powder in mines where there is
dangerous gas or inflammable dust, because the flame from the
explosion of black powder lasts from 2,500 to 3,500 times as long as
does the flame from these newer explosives, and is therefore more
likely to ignite the gas or dust in such mines.

A PRIMER ON EXPLOSIVES FOR COAL MINERS.

By C. E. MUNROE and CLARENCE HALL.

COMBUSTION AND EXPLOSION.

Fire. There is probably no activity of nature with which man is better acquainted or has been longer acquainted than with fire, of which he has made use from the earliest days for warming his body, cooking his food, giving him light, and in more recent times for breaking down rock, for making steam, and for other purposes. He has observed that a great number of substances can be burned, such as wood, charcoal, coal, sulphur, phos-

Combustible substances. phorus, magnesium, zinc, oil and gas in their many varieties, and many others, and he has made use of them to produce heat and light. He has noticed that when wood is burned in large sticks it is difficult to start the fire, and that where there are but a few large sticks the fire burns but slowly. When the wood is cut into kindlings and these are heaped together, they burn more rapidly. When the kindlings are cut into shavings and these are piled together, they burn still more rapidly; and when the wood is cut into dust by means of a saw and this dust is suspended in the air and set on fire, it burns with explosive rapidity.

The same thing is found to be true of the other substances that burn under ordinary circumstances and are therefore called combustible. That is, the more finely divided they are and the more intimately this finely divided material is mixed with the air, the more rapid is the burning or combustion. This intimate mixture with the air is best attained with gases such as marsh gas (the fire damp found in mines), coal gas such as is used for lighting, and acetylene, or with vapors such as those from gasoline; and when these are thus intimately mixed with the air the combustion goes on so rapidly that it

Explosion. takes the form of an explosion. Although an explosion is easily produced by mixing combustible gas or vapor and air in the right proportions, explosions may also be obtained by mixing combustible dusts with the air in the right

Dust explosions. proportions and igniting them; and therefore we are not surprised to hear that explosions have been occasioned by mixtures of sawdust or flour dust or starch or sugar or soap

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or coal dust with the air. Many explosions thus produced are very violent, and destroy life and property. (See Pls. II and III.)

In each of the kinds of combustion or explosion that have been spoken of the combustible substance is mixed with *Air necessary to ordinary combustion.* air, and that the presence of air is necessary for the combustion or burning is proved by the fact that when we cut off the air from contact with a burning body the fire goes out, or, as we say, we have smothered the fire.

The reason for this has been found in the nature of one of the several different substances that the air is composed of. *Oxygen of the air necessary for combustion.* This is the gas named oxygen, which is about one-fifth of the whole volume of the air. It is possible to separate this oxygen from the air, and when this has been done and burning bodies are brought into contact with this separated oxygen it is found that they burn much more rapidly than in air, and that the combustion is much more brilliant. By repeated experiment it has been proved that all ordinary combustion is caused by the combination of the combustible substance with this oxygen of the atmosphere. Air deprived of its oxygen will not support combustion or life.

In view of these facts, and in view, further, of the fact that there are other substances in nature besides air that contain oxygen and will give up this oxygen to combustible substances, it would seem probable that combustion could be brought about through the aid of such oxygen-containing bodies; and this was long ago proved to be true. One of the first, if not the first, of such bodies that became known to man is saltpeter, also called niter, or potassium nitrate, which, because it occurs as a white efflorescence, like frost, on the surface of the soil in India, has been called India saltpeter, although it has been found to some extent in many parts of the world.

If solid saltpeter in the dry condition is mixed quite thoroughly with a solid combustible substance, such as charcoal, *Saltpeter supports combustion.* the mixture burns easily when once it is ignited. The advantage of such a mixture is that the oxygen which is to support the combustion is in close contact with the charcoal which is to be burned, and that, therefore, this substance or mixture can be set afire and will burn without contact with the air, and will so continue to burn until the charcoal is completely consumed. As a result of the burning of the charcoal or carbon with the oxygen of the saltpeter a gas is formed. As *Charcoal with saltpeter produces heat and gas.* another result of the burning of this mixture of charcoal and saltpeter heat is produced, and this heat warms up the gas, so that if it is unconfined its volume becomes greatly expanded, and if it is confined it exerts pressure

EXPLOSION AT A COAL MINE NEAR NEWCASTLE, NEW SOUTH WALES.

and does work. Hence, if such a mixture be burned in the bore hole of a rock, it may break down the rock, or in the barrel of a gun, it will drive out the bullet.

It is found, however, that it is not easy to ignite such a mixture of charcoal and saltpeter, even when mixed in the best possible way, and to overcome this difficulty use is made of another substance that ignites easily, one which on burning gives out heat enough to ignite the mixture of charcoal and saltpeter. This substance is sulphur, or brimstone, such as has been used in the past for the tips of sulphur or brimstone matches, for which the same object of easy ignition was sought. So eventually the mixture has been made of charcoal and saltpeter and sulphur, which are finely ground and closely mixed and then formed into grains, and such a mixture is called gunpowder. As has been pointed out, it is simple combustion that takes place when such mixtures are set afire, but on account of the thoroughness of the mixing, the proportions in which the different substances are mixed, and the way in which the material is finally made into grains, this combustion may proceed so rapidly that there is an explosion, which is powerful because the solid mixture, occupying a very small space, gives on combustion a large volume of highly heated gases.

Sulphur is added to make the mixture ignite easily.

About 1821 there was discovered in the desert regions of Peru and Chile another saltpeter, sodium nitrate, which has come to be known by the name of Chile saltpeter. Like the India saltpeter, potassium nitrate, it contains oxygen, and it will give up its oxygen to combustible substances with ease at a relatively low temperature. Hence a mixture of it · with charcoal (known also as carbon) and sulphur makes a body similar to that produced with the India saltpeter, and since 1857 such a mixture has been extensively used, especially in this country, for blasting in rock and in mines.

Chile saltpeter contains oxygen.

Besides the India and the Chile saltpeters, many other solid substances that contain oxygen and will give up their oxygen easily, on heating, to combustible substances have become known, and many of them have been tried in the formation of explosive mixtures. Though one or two of them are used to some extent, as will be shown further on, none are used so largely as the saltpeters.

Oxygen in other bodies.

It has also been found that we can get the oxygen out of the saltpeters in other ways than by firing an explosive mixture, as, for instance, by heating either the India or the Chile saltpeter in a proper manner with sulphuric acid, when we obtain from them nitric acid, which contains all of the oxygen originally in the saltpeters. It has further been

Nitric acid from saltpeter.

learned that when substances like cotton or starch or glycerin are treated with nitric acid in the proper way there are

Putting oxygen into cotton, glycerin, etc. formed, from the cotton, guncotton, or nitrocellulose, as it is also called; from the starch, nitrostarch; from the glycerin, nitroglycerin; and through this means the cotton, the starch, and the glycerin, which are all combustible substances, are converted into substances much more highly explosive and more powerful than mixtures made with the saltpeter and sulphur and combustible substances. In fact, such bodies can be made to explode by a shock such as is produced by a detonator or blasting cap when fired in contact with them, and the explosion is extremely rapid and very much more powerful than that of the saltpeter mixtures.

It has also been found that by the action of alcohol upon nitric-acid solutions of metals, such as copper or silver or mercury, under proper precautions, substances may be formed which are still more sensitive and still more violent in their explosive effects than guncotton or nitroglycerin. The best known and the

Sensitiveness and violence of fulminate of mercury. most widely used of these substances is fulminate of mercury. When dry, this substance is so sensitive that a very slight blow, very little friction, or a slight rise in temperature will cause it to explode, and on explosion it produces a shattering effect upon any substance with which it is in contact. Moreover, the character of its explosion is such that if but a small mass of it is exploded in proper contact with guncotton or nitroglycerin or dynamite or other similar explosive, it will cause each of them to undergo a very violent explosion, which also will produce a shattering effect on the bodies with which they are in contact.

From what has been said it will be seen that there are at least two classes of explosives. One class is the saltpeter mixtures, in which an explosion is brought about by simple combustion that proceeds rapidly and gives rise to a large volume of highly heated gases, though almost one-half of the mass remains as a solid residue. Explosives

Low explosives. of this class exert a relatively slow pushing effect upon the substances with which they are in contact when they explode, and are called "low" explosives. In the other class are explosives of the character of guncotton and nitroglycerin, which undergo explosion by being suddenly and wholly resolved into a large volume of highly heated gases, the change proceeding many times faster than the combustion that takes place in the saltpeter class of explosives. Because of their speed and power these

High explosives. explosives have a shattering effect upon the substances with which they are in contact, and are known as "high" explosives, and also sometimes as detonating explosives.

EXPLOSION FROM COAL DUST IN GAS AND DUST GALLERY NO 1, PITTSBURG TESTING STATION

Every explosive, when exploded, exerts pressure in every direction. When laid on top of a rock and exploded, gunpowder and other low explosives do not affect the rock, because they explode so slowly that the gases formed can lift the air above them and escape; but dynamite, fulminate of mercury, and other high explosives, if laid upon brittle or soft rock and detonated, may shatter it, because they explode so quickly that the gases formed can not lift the large volume of air which confines them without pressing back forcibly against the rock. (See Pl. IV, *A*.) This confinement by air is not, however, close enough to give the best result with any explosive. By boring a hole in rock and tamping the explosive firmly in it, gunpowder and other low explosives may be made to break the rock, or a much less quantity of high explosive will break the rock than is required to break it when laid upon it. Confining an explosive is the cheapest and best way to use it.

Confinement essential to use of explosives.

It is foolish and dangerous for an inexperienced person to attempt to manufacture any kind of an explosive except under the supervision and direction of a trustworthy person who is skilled in the art. Many serious accidents, which have destroyed lives or inflicted injury on persons and property, have been caused by such attempts.

Folly of attempting to make explosives.

EXPLOSIVES.

As may be inferred from what has already been said, a large num-
ber of substances are known and used as explosives.

Gunpowder.

The one longest known and used is gunpowder, which
has certainly been used since early in the fourteenth century. This
is made by intimately mixing 75 parts of India saltpeter (potas-
sium nitrate) with 15 parts of charcoal and 10 parts of sulphur.
Each of these ingredients is ground to a fine powder, and then they
are ground together while moistened with water, in the proportions
given, until the mixing is complete. The material is pressed into
cakes, which are then broken up into grains, which are dried, glazed
by rubbing, and sorted by the aid of sieves into the various desired
sizes.

Formerly this India saltpeter powder was used both in guns and
in blasting, and while to-day some of it is used

Black blasting powder.

in blasting, the larger part of what is used in this
country under the name of black blasting powder is
composed of 73 parts of Chile saltpeter (sodium nitrate or nitrate of
soda), 16 parts of charcoal, and 11 parts of sulphur. This black blast-
ing powder is made in a manner similar to that described for gunpow-
der, but less time is spent in making the mixture, and the charcoal is
usually obtained from coarser-grained woods. The Chile saltpeter will
supply more oxygen, and supply it more easily, than the India
saltpeter, and therefore is a better and cheaper oxidizing agent; but
the Chile saltpeter is not used in the manufacture of gunpowder
because when it is exposed to moist air it takes up water by absorption
from the air and becomes wet. So powder or other

Danger from dampness.

explosives in which this Chile saltpeter (nitrate
of soda) is used likewise take up moisture when
exposed to the air and become damp, so that it is difficult, and
sometimes impossible, to set fire to them. As gunpowder for
use in guns and firearms must often be kept for a great many
years, and yet always be in such condition that it can be fired
at any moment with certainty, this property of absorbing moisture
from the air makes the nitrate of soda unfit for use in gunpowder;

Keep powder dry.

but blasting powder is not expected to be stored for
years, and in magazines at mines it is quite possible
to store it for a while so as to protect it from exposure to damp air.
Besides, by proper management it is possible to obtain this blasting
powder fresh from the manufacturer and use it promptly while in

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A. EXPLOSION OF HIGH EXPLOSIVE IN BOMB FILLED WITH WATER.

B. SCREENS FOR SEPARATING DIFFERENT-SIZED POWDER GRAINS.

that condition; hence advantage may be taken, for economic use, of the superior efficiency and cheapness of the nitrate of soda in the manufacture of blasting powders if we keep them dry.

Black blasting powder comes into the market in the form of grains whose edges have been rounded off by rubbing Granulating powder. together in a revolving barrel and which are usually coated on the surface, or glazed, as it is termed, with graphite, or black lead. The object in rounding and glazing the grains is to render them free running, and the glazing also serves to delay somewhat the taking up of moisture from the air by the grains.

The powder is divided into grades according to the size of grains, as separated and collected by sieves of different sizes Size of powder grains. of openings. (See Pl. IV, B.) The sizes most usually offered for sale are called CCC, CC, C, F, FF, FFF, and FFFF. Of these, CCC represents the largest grains, about five-eighths inch in diameter, and FFFF represents the smallest grains, about one-sixteenth inch in diameter. (See Pl. V, A.) The relation between the letters designating the sizes of the powder grains and the sieves by which the different sizes are separated is shown in the following table:

Relation between sizes of black blasting powder and separating sieve.

Size of grains.	Diameter of round holes in screens through which grains pass.	Diameter of round holes in screens on which grains collect.
CCC	inch	inch
CC	inch	inch
C	inch	inch
F	inch	inch
FF	inch	inch
FFF	inch	inch
FFFF	inch	(a) inch

a Or 28-mesh bolting cloth.

To get the best results in the use of this powder in ordinary blasting, the grains should be of uniform size, so that Danger in using a mixture of different sized grains. the miner, having determined the best size of charge, may have no difficulty in repeating it. Unfortunately not enough care is taken in separating the grains into the different sizes, and powders have appeared in the market in which a considerable number of different sizes of grains were mixed together, so that the miner has obtained quite different results from his different shots in the same mine of coal with the same grade of powder. (See Pl. V, B.) Moreover, where large and small grains of powder are mixed in a charge, the fine grains, which

burn freely, may produce in burning enough pressure to throw the large grains out into the mine where they can set the gas and dust afire. This makes such a mixture of grains a dangerous one in use.

It has already been said that many other substances besides

Potassium chlorate. India saltpeter (potassium nitrate) and Chile saltpeter (sodium nitrate) are known which contain oxygen in such quantity and in such manner that they may be used as the oxidizing agents in forming explosives. Among these is the substance known as potassium chlorate. More than 100 years ago an eminent French chemist showed that when it was mixed with combustible substances a most powerful explosive was produced; but, unfortunately, this mixture was found to be so sensitive to friction, blows, and heat as to endanger the lives of those who sought to handle and use it. Many of the mixtures produced with potassium chlorate are so easy to prepare and explode with such violence that a great many persons have been tempted to make them, but until recently all those that have been devised have been rejected as unfit for use because they were liable to destroy those who attempted to make or use them. It is found, however, that when dry and finely ground potassium chlorate is mixed with a body like starch, and with oil and other substances, an explosive is produced that is fairly safe to handle. Mixtures of this nature have met with some use in Europe.

Attention has also been called (p. 14) to the fact that when puri-

Nitrocellulose. fied dry cotton is immersed in nitric acid in the proper manner it is changed into an explosive substance through reaction with the nitric acid. When we withdraw the fibrous cotton from the nitric acid, wash it thoroughly to remove any acid that sticks to it, and then carefully dry it at a low temperature, the cotton appears unchanged to the eye, even when examined most carefully. It has, however, become a little harsh to the touch. When rubbed, it becomes electrified so that it sticks to the fingers, and when a flame is applied to it, flashes off with great rapidity. In practice, a mixture of sulphuric acid is used with the nitric acid in nitrating the cotton. By varying the strength and the proportions of the nitric and sulphuric acids, their temperature when the cotton is dipped in them, and the length of time that the cotton is in them, we can get a number of different products varying in the rate at which they will burn and in the degree to which they are soluble in various solvents; but every such product results from the replacement of more or less of the element known as hydrogen, which was present in the cotton, by nitrogen and oxygen (indicated by the formula NO_2), which came from the nitric acid. Such a product, obtained by the action of the nitric acid on the cotton, will take
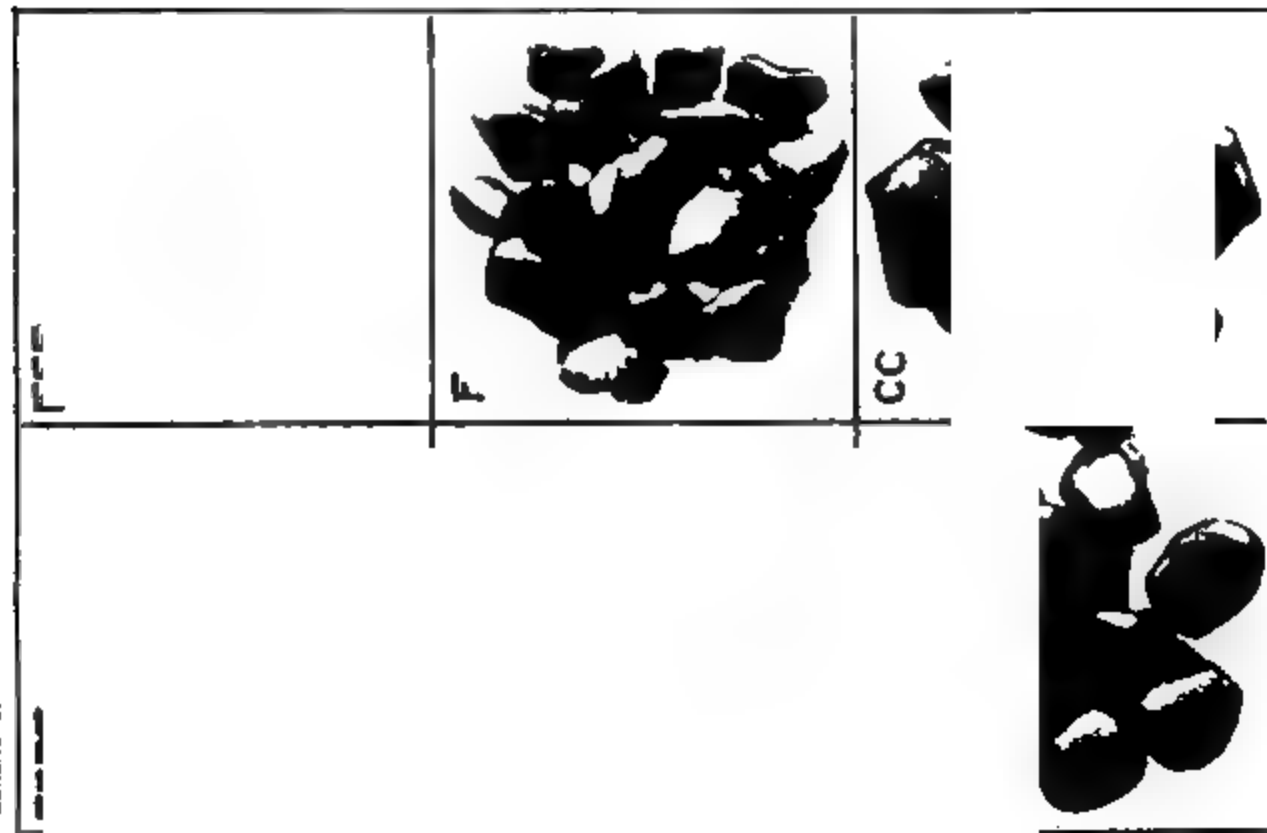
B. MIXTURE OF DIFFERENT-SIZED GRAINS OF BLACK BLASTING POWDER

A. GRAINS OF BLACK BLASTING POWDER.

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fire and burn the more easily the greater the number of NO_2 groups that have replaced hydrogen in the cotton. We may, for convenience, divide these various products into two classes. Those which contain the fewer of these NO_2 groups are called pyroxylin, or soluble nitrocellulose, or collodion cotton, and those which contain the greater number of the NO_2 groups are known as gun cotton. In the manufacture of gun cotton the very strongest nitric and sulphuric acids are used. After the product has been washed so as to remove most of the acid sticking to it, it is pulped while wet into a fine powder in a machine such as is used in pulping paper stock, and when the gun cotton has been washed in this powdered condition so as to remove the last traces of acid, it is molded into blocks and is used as an explosive in that form.

Nitroglycerin is prepared by slowly running glycerin into a

Nitroglycerin. mixture of the strongest nitric and sulphuric acids, the whole being stirred and kept cool during the process of mixing. The reaction which takes place between the glycerin and the nitric acid is similar to that which takes place with the cotton. As a result of the reaction, NO_2 groups from the nitric acid replace hydrogen in the glycerin, and the mild, sweet, harmless glycerin is thereby changed into the powerful and dangerous explosive nitroglycerin. Nitroglycerin is a rather dense oil-like liquid. When pure it is colorless, but as it appears in the market it is usually pale yellow. It is somewhat poisonous, and one can be poisoned by it not only through the mouth but also by breathing its vapors or by allowing the liquid to touch the skin. A drop of it touching the tip of the finger will usually soon produce a violent headache. Fortunately, most persons lose their sensitiveness to poisoning after repeated contact, so that they cease to have the headache, but it

Nitroglycerin would still be dangerous for these persons to get any
freezes. of the nitroglycerin into the mouth. Nitroglycerin may freeze after some exposure to a temperature of 52° F. (see p. 27) and it must be thawed before it can be properly used as an explosive.

Being a liquid, nitroglycerin is especially dangerous for ordinary use, because it may escape from the cans or other
Liquid nitro- vessels in which it is carried or stored and run off
glycerin is especially
dangerous. to considerable distances, so as to increase the chances of accidental explosion by a blow, or friction, or heat; and also because it may, when placed in a bore hole, leak out into crevices or seams in the rock, and when fired give most undesirable results. In fact, during the middle of the last century, when it was offered for use, so many accidents occurred that many countries, by law, forbade its use or manufacture. We can, however, prevent a

liquid from flowing about by absorbing it in a porous body, like a sponge. This has been done with nitroglycerin, and the product is called dynamite. Dynamite consists of nitroglycerin absorbed in a solid body called the dope. There are many dynamites. One of the earliest known and used was made by absorbing the nitroglycerin in powdered "rotten stone." As the "rotten stone" could neither burn nor explode, it was called an inactive dope, and there are several varieties of dynamites with inactive dopes. On the other hand, nitroglycerin may be absorbed in gunpowder. As the gunpowder explodes, as well as the nitroglycerin, when the dynamite is fired, the gunpowder is called an active dope. There are a large number of dynamites made with active dopes, and with varying percentages of nitroglycerin. The standard straight dynamite used at the Pittsburg testing station may be taken as an example of a dynamite with an active dope. It consists of the following:

Dynamite.

Composition of standard straight dynamite.

	Per cent.
Nitroglycerin	40
Nitrate of soda (sodium nitrate)	44
Wood pulp	15
Carbonate of lime (calcium carbonate)	1
	100

Since it is a liquid, nitroglycerin, like other liquids, acts as a solvent, and it has been found that under certain conditions it can dissolve soluble nitrocellulose, and that the mixture thus formed will set to a jelly-like mass. In this way, or sometimes by the use of other solvents also, the substance known as explosive gelatin is formed, a substance that in some respects is regarded as the most nearly "ideal" explosive. However, it is too powerful for ordinary use in blasting, and it is therefore diluted by mixing it with a dope, such as the nitrate of soda and wood pulp used in straight dynamite. The mixture so formed is known as gelatin dynamite.

Explosive gelatin and gelatin dynamite.

It has already been said that nitroglycerin when exposed to ordinary winter temperatures will freeze. Dynamite, explosive gelatin, and gelatin dynamite will also freeze, because all of them contain nitroglycerin, and, like nitroglycerin, all of these substances should be properly thawed before any attempt is made to use them.

All explosives containing nitroglycerin freeze.

Each of these substances is put upon the market in the form of sticks or cartridges, which are made by wrapping up cylinders of the material in paper. The wrappers for dynamite and gelatin dynamite are paraffined to protect them from the action of water and the moisture in

Dynamite cartridges.

the air, because they contain nitrate of soda and hence may absorb moisture and become spoiled, and develop new sources of danger in handling and use. These sticks usually vary in size from seven-eighths inch to 2½ inches in diameter, and they are usually 8 inches

Packing dynamite.

long. They are usually packed in cases containing 50 pounds each. The mark "This side up," or a design on the top of the case, shows the position in which the cartridges are packed. The cases should always be placed so that the cartridges lie on their sides, and they do lie so when the cases are stored with their top sides up.

For use in coal mines it is suggested that the explosive be packed in cases or cartons containing the weight which the law of the district permits being taken into the mine. (See Pl. VI, *B.*)

Besides cotton and glycerin, there are a large number of substances, such as sugar and starch, that are chemically related to cotton and glycerin and through the action of nitric acid, particularly in the presence of sulphuric acid, give rise to explosive substances. Many

Nitrostarch.

of these have been produced, but so-called nitrostarch is the only one that seems to have any commercial importance. During the last 10 years this has attracted some attention, and it has been offered for use both in this country and in Europe. It is a finely powdered substance like starch itself, but it does not need, as starch does, to be suspended in the air in order to explode on ignition, because even when in a pile it will burn with great rapidity if set afire, and through the action of a detonator it explodes with great violence. It is not yet used by itself, but is used as a component in various explosive mixtures, particularly dynamites.

Attention has been called to the use of potassium nitrate and so-dium nitrate in the manufacture of explosives. In

Ammonium ni-
trate.

recent years another nitrate, formed by the union of ammonia with nitric acid and known as ammonium nitrate, has come to be somewhat largely used. It has been used in this country for more than a quarter of a century in the manufacture of some dynamites, taking the place of sodium nitrate and having the advantage over it that on explosion it goes completely into gases; but it has come to be used in Europe in the manufacture of special explosives for use in coal mines, for the reason that on explosion it forms a large amount of water, and this lowers the temperature of all the products of the explosion. In the making of several of these ammonium-nitrate powders, various substances obtained from coal tar, which generally have been acted upon by nitric acid, are mixed with the ammonium nitrate.

The substances derived from the coal tar, after having been acted upon by the nitric acid, are known as nitrosubstitution compounds. One of the best and longest known of the substances obtained from coal tar is carbolic acid, and when this acid reacts with strong nitric acid it gives us the nitrosubstitution compound known as picric acid. Other substances obtained from coal tar that are pretty well known are benzene, toluene, and naphthalene. When these are acted upon by nitric acid we obtain from them the nitrosubstitution compounds known as nitrobenzene, nitrotoluene, and nitronaphthalene. These are but a few of the many substances that may be obtained from coal tar and furnish, through the action of nitric acid upon them, nitrosubstitution compounds. All the nitrosubstitution compounds will form explosives when mixed with oxidizing agents such as ammonium nitrate, or other nitrates, or chlorates, and many explosives have been made from such mixtures. Moreover, these nitrosubstitution compounds have been used as components of dynamites, particularly because they lower the freezing point of the nitroglycerin in the dynamites.

Nitrosubstitution compounds.

The nitrosubstitution compounds are so called because the NO_2 groups in them, obtained from the nitric acid, are directly connected to the carbon atoms in the original material, replacing hydrogen atoms; whereas in gun cotton, nitroglycerin, and bodies of that sort, the NO_2 groups are linked to the carbon atoms of the original substance by means of atoms of oxygen. The nitrosubstitution compounds are usually yellowish to red crystalline solids, but as most of these solids are easily melted, they are often sent out in compact masses. A few of them are liquids at ordinary temperatures, and they have a marked aromatic odor. Some of these substances are poisonous. Great care should be taken in handling all of them, and one should especially avoid breathing their vapors.

Why nitrosubstitution compounds are so called.

As has been stated above, the most common fulminates are produced by dissolving a metal, such as mercury, in a strong nitric acid, and pouring the solution into common alcohol. When the proportions used are correct and the operation is carried out in a proper manner, after an apparently violent reaction there will be produced a mass of fine, gray crystals that look quite alike. These crystals are fulminate of mercury, or mercury fulminate. The crystalline powder thus produced is washed with water to free it from acids, and because of its extreme sensitiveness it is kept soaked with water until desired for use. It is principally used in loading blasting caps or detonators, and for this purpose the water may be removed from it by alcohol and it may be loaded into

Fulminates.

the copper capsules while wet with alcohol, but it should be always borne in mind that this mercury fulminate, even when thoroughly soaked with or sunk under water or alcohol, will **Danger with ful-** explode with tremendous violence if only a small **minates.** amount of the dry fulminate be exploded while touching it, or very near it. Hence extreme precautions should always be taken with mercury fulminate, whether the substance be wet or dry.

The manufacture of explosives is by no means simple. Unless all the materials are of the proper kind and in the proper **Warning against** condition, and they are used in the proper order, in **manufacturing ex-** **plosives.** the proper manner, with the proper tools and vessels, and with all the proper precautions at each stage of the operation, the manufacture is a very dangerous thing to undertake and it is very foolish for anyone to undertake it by himself.

EXPLOSIVES FOR USE IN COAL MINES.

It is evident that a large number of different explosives can be formed by mixing various combustible substances with various oxidizing agents, or by using such mixtures as dopes for dynamite, or by using them together with the different nitrosubstitution compounds. In fact, the number is so great that a book published in 1895 gave the names of more than 1,000 different explosives, and many have been added to the list since that date. As the number of those in actual use is much smaller, it is clear that most of the explosives known are, for various reasons, unsuitable for use; indeed, no one of those more generally known is suitable for use under all circumstances. For instance, some of them on explosion give off a considerable volume of flame; some of them on explosion give off considerable volumes of poisonous or noxious gases; some of them explode so quickly as to shatter the rock or other material in which they are fired and break it down into fine pieces; some of them are too bulky; and so on.

Number of explosives.

It is evident that if we are seeking to break down the rock in an open quarry for the purpose of making use of that rock as ballast for roads, we can employ an explosive that produces a long flame, or gives off poisonous gases, or shatters the material, because the work is done in the open air, and because the rock has to be broken up into small pieces anyway, so that it is well for the explosive to do it. If, however, we sought to get out from that quarry blocks of stone such as marble or granite, which were to be used in building or for monuments, we should avoid using the shattering explosive and choose one that slowly, and without a shock, separates the rock mass from the deposit. Yet for this purpose also, as the work is in the open air, it might matter little if the explosive gave rise to a large flame or gave off poisonous gases, provided the quantity of explosive used was small. But the conditions in a coal mine are very different from those in a quarry. The mine is inclosed and not out in the open air, and, moreover, it is liable at any time to contain inflammable gases or coal dust, or both, which may form explosive mixtures with the air. If under these circumstances an explosive were used which gave off a long flame on firing, this flame, darting out from the bore hole, might set fire to the explosive mixture in the mine and produce a mine explosion. (See Pl. VI, A.)

Explosives in open work.

Explosives in inclosed work.

Danger from flames in coal mines.

24

R.P.M. 37.5. Duration of flame, 1539 millisec., height of flame, 50.21 in.
A BLACK BLASTING POWDER

R.P.M. 2400. Duration of flame, .342 millisec.; height of flame, 1979 in.
A PERMISSIBLE EXPLOSIVE

A. FLAMES FROM EXPLOSION OF EQUAL WEIGHTS OF BLACK BLASTING POWDER AND OF A
PERMISSIBLE EXPLOSIVE.

B. BOXES OF DYNAMITE, SHOWING METHOD OF PACKING IT.

C. THAWER FOR FROZEN EXPLOSIVES.

Moreover, as the mine is an inclosed space and as the wholesome-
ness of the air within it depends upon artificial ven-
Noxious gases.   tilation, it is also objectionable in such a mine to
make use of an explosive giving off any considerable quantity of
noxious gases, which must be removed from the mine after the
explosion before the miner can safely return to his work.

Considerations such as these have led to an investigation by the
Bureau of Mines of the explosives offered in the mar-
Investigation by   ket, for the purpose of determining, in the interest of
Bureau of Mines.   the coal miner, which of such explosives are suitable
for use in coal mines and will do the work with.the greatest degree
of safety for the miner using them. Of course it is impossible to
insure complete safety, for no explosive can be perfectly safe and
every explosive should be treated with the greatest care and con-
sideration.

With this object in view the Bureau of Mines has a testing station
established at Pittsburg, Pa. (see Pl. I, frontispiece),
Testing station at   where there has been erected a large gallery made of
Pittsburg.
Explosives gallery   steel, 100 feet long by 6 feet 4 inches in diameter, and
No. 1.   so made that it can be filled with fire damp, or with
coal dust and air mixed, or with gas, dust, and air mixed in any
desired proportion, so as to reproduce the dangerous conditions that
may occur in coal mines. Attached to one end of the gallery is a very
strong "gun" with a chamber representing the bore hole in a mine.
From this "gun" various exactly determined quantities of the explo-
sive to be tested may be fired, either untamped or tamped, into the
mixture in the gallery, and thereby it can be learned whether or not
the definitely known quantity of explosive used as described will cause
the ignition and explosion of the mixture in the gallery. Besides
this gas and dust gallery there is at the testing station a collection of
other apparatus and appliances by which to test the various proper-
ties of explosives, and so to find their relative value and their relative
safety for use in coal mines. This investigation has been going on
since September, 1908, and there have already been published four
lists of explosives that have passed all test requirements in a satisfac-
tory manner and are considered to be suitable for use in coal mines,
provided they are used under the prescribed conditions.[a]

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[a] See p. 68 for prescribed conditions under which each of these explosives is to be used.

These explosives are, therefore, called by the Bureau of Mines "permissible explosives." The name of each brand that had passed the tests up to January 1, 1911, together with the name of the manufacturer, is given in the following list:

Permissible explosives.

Permissible explosives tested prior to Jan. 1, 1911.

Brand.	Manufacturer.
Aetna coal powder A	Aetna Powder Co., Chicago, Ill.
Aetna coal powder AA	Do.
Aetna coal powder B	Do.
Aetna coal powder C	Do.
Aetna coal powder D	Do.
Bental coal powder No. 2	Independent Powder Co. of Missouri, Joplin, Mo.
Bituminite No. 1	Jefferson Powder Co., Birmingham, Ala.
Bituminite No. 3	Do.
Bituminite No. 4	Do.
Bituminite No. 5	Do.
Bituminite No. 7	Do.
Black Diamond No. 3	Illinois Powder Manufacturing Co., St. Louis, Mo.
Black Diamond No. 4	Do.
Carbonite No. 1	E. I. du Pont de Nemours Powder Co., Wilmington, Del.
Carbonite No. 2	Do.
Carbonite No. 3	Do.
Carbonite No. 4	Do.
Carbonite No. 1-L. F	Do.
Carbonite No. 2-L. F	Do.
Coalite No. 1	Potts Powder Co., New York City
Coalite No. 2-D	Do.
Coalite No. 2-D. L	Do.
Coalite No. 3-X	Do.
Coal special No. 1	Keystone National Powder Co., Emporium, Pa.
Coal special No. 2	Do.
Coal special No. 3-C	Do.
Coal special No. 2-W	Do.
Coal special No. 3-W	Do.
Coal special No. 4	Do.
Coal special No. 5-L. F	Do.
Collier powder No. 2	Do.
Collier powder No. 4	Do.
Collier powder No. 5	Do.
Collier powder No. 5 special	Do.
Collier powder No. 5-L. F	Do.
Collier powder No. X	Do.
Collier powder No. 2-L. F	Do.
Collier powder No. 3	Do.
Collier powder No. 6-L. F	Do.
Collier powder No. 8-L. F	Do.
Detonite special	The Detonite Co., Cincinnati, Ohio.
Eureka No. 2-L. F	G. R. McAbee Powder & Oil Co., Pittsburg, Pa.
Giant A low-flame dynamite	Giant Powder Co. (Consolidated), Giant, Cal.
Giant B low-flame dynamite	Do.
Giant C low-flame dynamite	Do.
Hecla No. 2	E. I. du Pont de Nemours Powder Co., Wilmington, Del.
Kanite A	W. H. Blumenstein Chemical Works, Pottsville, Pa.
Masurite M. L. F	Masurite Explosives Co., Sharon, Pa.
Meteor AXXO	E. I. du Pont de Nemours Powder Co., Wilmington, Del.
Mine-ite A	Burton Powder Co., Pittsburg, Pa.
Mine-ite B	Do.
Monobel No. 1	E. I. du Pont de Nemours Powder Co., Wilmington. Del.
Monobel No. 2	Do.
Monobel No. 3	Do.
Nitro low-flame No. 1	Nitro Powder Co., Kingston, N. Y
Nitro low-flame No. 2	Do.
Titanite No. 3-P	Waclark Titanite Explosive Co., Corry, Pa.
Titanite No. 7-P	Do.
Titanite No. 8-P	Do.
Trojan coal powder A	Pennsylvania Trojan Powder Co., Allentown, Pa
Trojan coal powder B	Do.
Trojan coal powder C	Do.
Trojan coal powder D	Do.
Trojan coal powder E	Do.
Trojan coal powder F	Do.
Tunnelite No. 5	G. R. McAbee Powder & Oil Co., Pittsburg, Pa.
Tunnelite No. 6	Do.
Tunnelite No. 7	Do.
Tunnelite No. 8	Do.
Tunnelite No. 6-L. F	Do.
Tunnelite No. 8-L. F	Do.

With reference to the characteristic component of each of these permissible explosives, they may be placed in four

Classification of permissible explosives.

classes—ammonium nitrate powders, represented by Aetna coal powder AA, Bental coal powder No. 2, Bituminite No. 5, Bituminite No. 7, Coalite No. 3-X, Coal special No. 4, Collier powder No. 5, Collier powder No. 3, Collier powder No. 5 special, Collier powder No. 5-L. F., Collier powder No. X, Detonite special, Hecla No. 2, Kanite A, Masurite M. L. F., Monobel No. 1, Monobel No. 2, Monobel No. 3, Titanite No. 3-P, Titanite No. 7-P, and Titanite No. 8-P; hydrated powders, represented by Meteor AXXO, and Giant low-flame dynamite A, B, and C; nitrostarch powders, represented by Trojan coal powders A, B, C, D, E, and F; and nitroglycerin powders, represented by all the others on the list.

The explosives on the list which are marked L. F. contain nitro-substitution compounds or other materials which have been added to lower their freezing points.

With the exception of Detonite special, Hecla No. 2, Kanite A, Masurite M. L. F., Titanite No. 3-P, Titanite No. 7-P, Titanite No. 8-P, and the Trojan coal powders A, B, C, D, E, and F, all of the powders mentioned in the list contain nitroglycerin, and they are all of the general nature of dynamite; but the components and proportions of the dopes have been so chosen and the mixtures so made as to modify greatly the shattering effect upon explosion and to yield a relatively cool flame. As a result, the flames produced are short and not lasting, and coal is thrown out without being

Advantages of permissible explosives.

powdered, when the proper charge of such an explosive is used and this charge is properly placed. These explosives are designed to take the place of black blasting powder, which has been found to be unsuited for use in coal mines where dangerous gas or inflammable dust is present, because of the great mass of flame which it produces and the long time that this flame lasts, and because of the quantity of poisonous smoke and noxious gases which it gives out when exploded. Although explosives of the kind represented in the list of permissible explosives have been introduced into this country only during the last few years, yet their consumption now amounts to several million pounds annually and is rapidly growing.

Unfortunately, though the permissible explosives are good coal getters and yield short flames that do not last and

Danger from permissible explosives.

gases of low temperature, so that there is little danger of igniting the explosive gases and dusts in mines when they are used, still the gases they yield on explosion may be noxious and inflammable; and miners are warned, when using permissible explosives, not to return to the breast after firing them any

sooner than they would if they had fired a charge of black blasting powder.

From what has been said regarding nitroglycerin, it follows that all these permissible explosives, except Detonite special, Hecla No. 2, Kanite A, Masurite M. L. F., Titanite No. 3-P, Titanite No. 7-P, Titanite No. 8-P, and Trojan coal powder, A, B, C, D, E, and F will freeze when exposed long enough to low temperatures, and then they must be thawed before they can be properly used. It is true that in making several of them, especially those marked L. F., materials have been added that prevent their freezing so readily, but the manufacturers do not claim that such explosives will remain unfrozen when the temperature falls below 35° F. To keep any of the nitroglycerin explosives permanently thawed, they should be stored where the temperature does not go below 52° F. On the other hand, care should be taken that none of these explosives is subjected to high temperatures, for this will render all of them more sensitive to explosion and is likely to cause the decomposition of some of them. It is best that the temperature of magazines in which they are stored should not rise above 90° F.

Freezing of permissible explosives.

Danger from exposure to high temperatures.

Explosives should not be exposed for any length of time to direct sunlight, because this may lead to decomposition in those containing nitroglycerin, nitrocellulose, nitrostarch, or substances of that kind. Explosives should be stored in a dry place, for many of them contain considerable quantities of ammonium nitrate or of sodium nitrate and so will take up moisture from damp air and become damp. Too great dampness makes the explosive not only harder to fire, but weaker when fired. Besides, if the explosive is damp the nature of the gases produced will be different. Moreover, as bodies like dynamite become moist, the nitroglycerin contained in them tends to run out; that is, what is called exudation takes place, and all the dangers follow that belong to liquid nitroglycerin.

Do not expose to sunlight.

Keep explosives dry.

On the other hand, explosives should not be kept in an extremely dry place, for all of them, as made, contain some moisture, and if the place of storage is very dry the explosive may lose this moisture. Such a change in composition will affect the explosive so as to change the speed with which the explosive reaction takes place within it, and therefore the character of the work which it does when exploded.

Do not dry explosives too much.

Naturally, the longer an explosive is kept in storage the greater are the chances that change will take place in it, and therefore the explosive should be obtained in as fresh a condition as possible and should be used as

Use explosives promptly.

soon as possible after it is received. Also, it should be kept stored in its original packages in the magazine outside the mine until wanted for immediate use, and then used promptly.

Dynamite is put up in sticks, which are wrapped in paper, and the cartridges so formed are usually dipped in paraffin to

Injury to car-
tridges from rough
handling.

make the wrapping waterproof. As by rough handling the folded edges may be broken open and the contents of the cartridge thereby exposed to the moisture of the air, these cartridges should be handled with great care, and they are best carried to the place where they are to be used in the cartons in which they are bought.

In handling explosives the greatest care must be taken to prevent their falling or getting shocks. They must not be

Care in handling
cartridges.

thrown or dropped, and portions of the powder falling from the cartridges must be carefully guarded against friction, blows, or fire.

Explosives should never be carried by railroad except in conformity with the rules of the Interstate Commerce Commis-

Shipment of explo-
sives.

sion, as published by the American Railway Association. These rules make it unlawful to carry any explosives, except small-arms ammunition, on any public vessel or vehicle carrying passengers.

Explosives should be stored in properly placed, built, and aired magazines. Such a magazine should be far enough

Storage of explo-
sives.

from other buildings or works so that if an accidental explosion occurred when the magazine was full it would do the least possible damage, and it should be so placed as not to be in danger from forest, brush, or other accidental fires. Magazines are best built of cement mortar, but they are more

Magazines.

frequently built of brick or of wood covered with corrugated iron. In any case they should be provided with wooden floors, which should be kept free from grit and dirt. It is best that only one kind of explosive should be kept in any one magazine. If more than one kind of explosive (other than permissible explosives) must be kept in the same magazine, the magazine should be divided into rooms, by partitions, and the different explosives kept

Detonators never
to be stored with
other explosives.

in different rooms. On no account should detonators, or blasting caps, or any device containing fulminating composition, be kept in the same magazine with any other explosive. These firing devices should be kept in a dry place by themselves.

Plans and specifications for magazines will be furnished by manufacturers of permissible explosives. (See also pp. 61–63, and figs. 11 and 12.)

The greatest care must be taken to prevent packages of explosives from falling or getting shocks. They must not be thrown, dropped, nor rolled. Wooden boxes containing explosives should be opened with extreme care, so as to avoid friction and blows as much as possible. They should never be opened within the magazine, but in a properly sheltered place outside of the magazine and at a distance from it. They should be opened only by the use of a wooden mallet and a hardwood wedge.

Opening boxes of explosives.

The thawing of frozen explosives requires extreme care, and doing it improperly has frequently led to most serious accidents. No attempt should ever be made to thaw a frozen explosive by placing the cartridge before a fire, or near a boiler, or on steam pipes, or by putting it in hot water, or by placing it in the sun. While being thawed, nitroglycerin explosives are extremely sensitive and should be handled with great care. During the thawing the nitroglycerin tends to separate from the dope and run out from the cartridge (that is, to exude), and this is a source of danger.

Thawing frozen explosives.

When but a small amount of the explosive is required, it may be thawed in a thawer such as is furnished by all the manufacturers of explosives and has been found safe for use as directed. (See Pl. VI, *C*.) The thawer consists of a water-jacketed tin vessel, in which the cartridges are placed and which is closed with a tin cover. Before the water is placed in the vessel it is warmed up to a temperature not uncomfortable to the hand put into it, and the cartridges are allowed to remain in the thawer until it is found, by gently pressing them, that they are completely thawed throughout. When thawed, the material will feel plastic, or like flour, between the fingers. When frozen, or partly frozen, the stick will feel more or less rigid and hard. It is necessary that the stick should be thawed completely, because dynamite when frozen can be detonated only with great difficulty, and any part that is frozen will be but
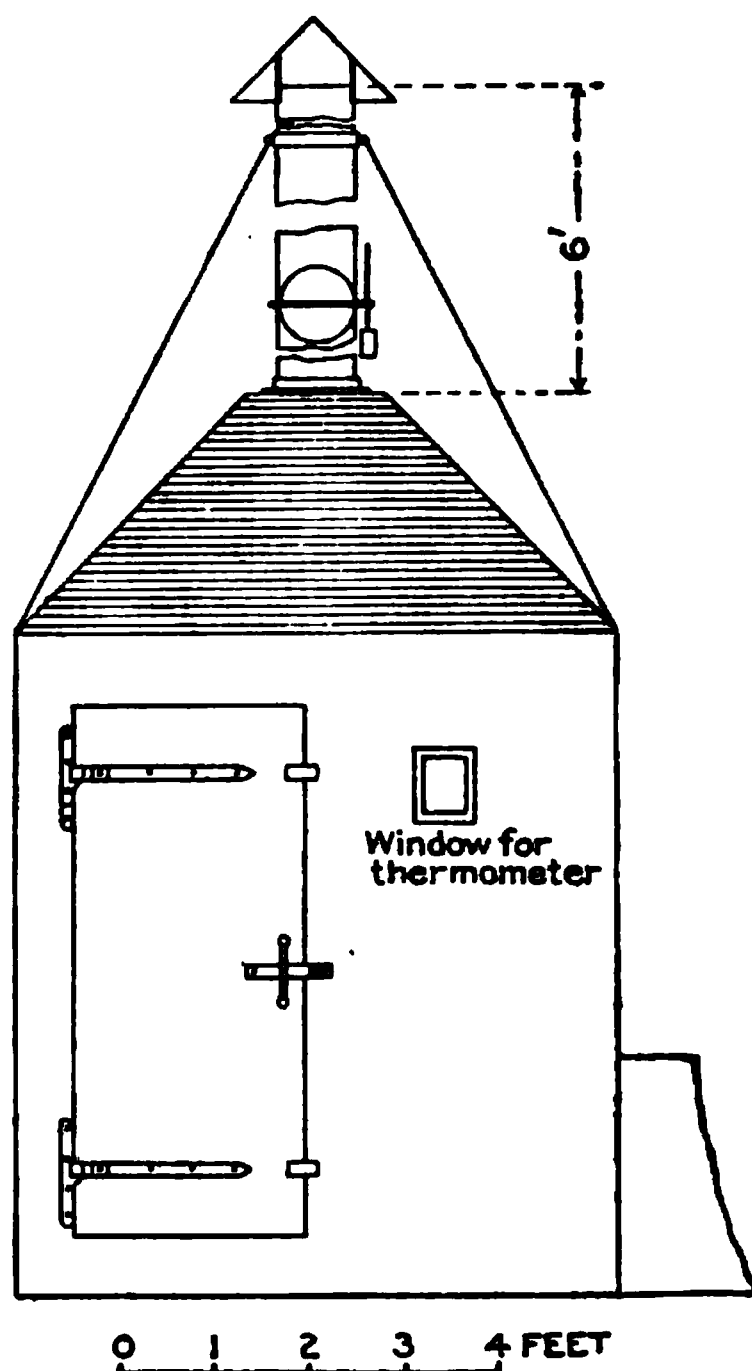
Thawers for explosives.

Complete thawing necessary.

FIGURE 1.—Thaw house for frozen explosives: elevation.

Window for thermometer

0   1   2   3   4 FEET

imperfectly detonated in the hole; hence not only may such partly frozen powder fail to give its full effect as an explosive, but there is danger of a serious accident in a coal mine where such powder is used, because if a blown-out shot results the burning solid part may set fire to the dust or fire damp in the air of the mine.

Where large quantities of explosives are used daily, a small thaw house should be provided for the purpose of thawing

Thaw houses.

out the frozen explosive. (See figs. 1 and 2.) Plans and specifications, together with a bill of material for such a thaw
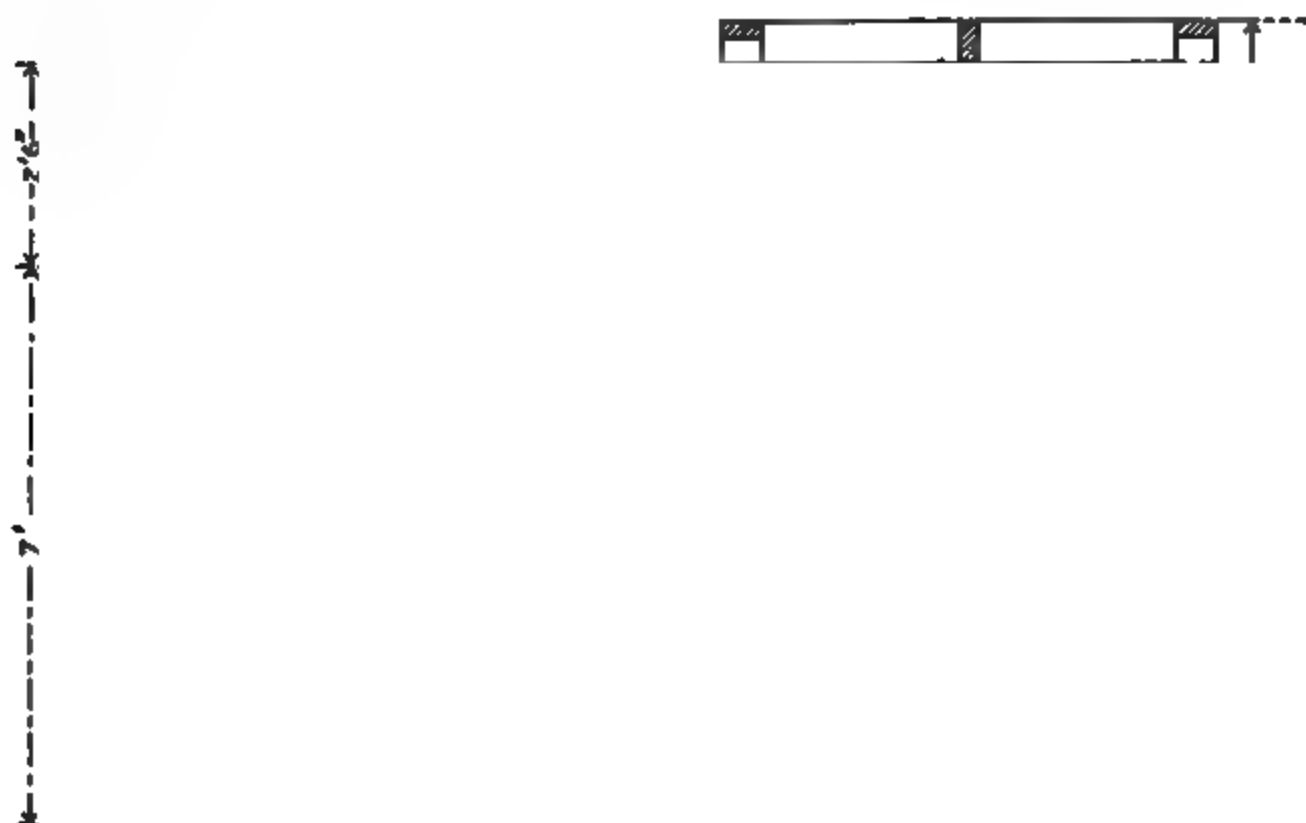
SECTION C-D

FIGURE 2.—Thaw house for frozen explosives; section. The cement mortar in the walls is made of 1 part cement and 6 parts sand.

house, will be furnished, on application, by the manufacturers of permissible explosives. The thaw house should be large enough to hold all the explosives used in one day's work. It should be heated by a small hot-water heater, placed at least 4 yards from the house,

the hot water being passed into the house through iron pipes, at such a rate that the temperature in the house will not at any time be above 90° F.

Thaw houses are intended only for the treatment of explosives for immediate use, and not for the storage of explosives,

Thaw houses not to be used for storage. for if powders or dynamites are left in this high temperature and dry air for a considerable time, the moisture that is a proper part of them will be driven off, and, as stated before, this will markedly alter the character of the powder or dynamite and may lead to accidents in its use.

A. MINER'S SQUIB.

B. MINER'S SQUIB AND FUSE.

SQUIBS, FUSE, AND DETONATORS.

It has been made clear in the discussion of combustion and explo-
sion and the description of various explosives that they
can be caused to explode by various means. All of
them can, under some circumstances, be made to
explode by fire. Some of them can be caused to undergo a detonating
explosion by setting off a detonator in contact with them. In blasting
use is made of both these means for setting off explosives, the means
used being determined by circumstances.

In setting off by means of fire, use is made of miner's squibs, or of
fuse. Miner's squibs (Pl. VII, *A*) consist of tapering
paper tubes about 7 inches long, filled with fine gun-
powder, one end of each paper tube being treated with chemicals
so as to form a slow-burning match, which, when ignited, burns so
slowly as to give the miner time to reach a place of safety before
the explosion. When used the squib is placed in the needle hole,
or blasting barrel, through the tamping, with the match end of the
squib outward. When the match is ignited the fire burns slowly
along the tube until it reaches the powder core.
Then the squib darts forward like a rocket, leaving
a trail of flame behind which spurts out from the needle hole, and
the fire continues burning along the powder core of the squib until it
bursts out of the other end of the tube and so ignites the charge.

In experiments made at the Pittsburg testing station it has been
found that, though the burning match on the end of
the tube of the squib does not inflame a mixture of
mine gas and air, as soon as the powder core is
ignited the flame that then flashes out from the end
of the squib will explode the mixture. Hence squibs should not be
used in any gaseous mine.

Fuse, as used in coal mines, is sent out into the market in coils
50 feet long, and in several varieties, but all consist
of a core of mealed gunpowder inclosed in two or
more layers of yarn and generally surrounded by tape that has
been dipped in a waterproofing composition. (See Pl. VII, *B*.)
Some varieties are then dusted with substances like powdered soap-
stone, to prevent the sticky surfaces from sticking to one another.
The kinds of fuse most commonly used are hemp fuse, cotton fuse,
single-tape fuse, double-tape fuse, triple-tape fuse.

Side notes:
Means of exploding explosives.
Miner's squibs.
How squibs work.
Squibs should not be used in fiery mines.
Fuse.

When one end of a fuse of any variety is lighted the powder core burns slowly along the fuse till at last the flame rushes out at the farther end and, if it touches a charge of powder, sets it off. Like squibs, fuse throws off flame when lighted, and hence the use of fuse in a gaseous mine can not be recommended.

Action of fuse.

Fuse should be so made and should be in such a condition when used that any part of any coil will burn at a rate that does not vary more than 10 per cent above or below the standard rate. This is of the greatest importance, because in setting a charge the blaster or shot firer cuts a piece of fuse to reach from the charge to the opening and long enough to give him ample time, after the end has been set on fire, to reach a place of safety before the flame fires the charge. In order that a fuse may burn at a regular rate, the powder core of the fuse should be uniform in character and should extend continuously through the fuse. Examinations of fuses by the X ray have shown that sometimes the powder does not extend continuously through the fuse, but that there are spaces between the portions of the core (Pl. VIII, *A*). Therefore, careful tests should be made of the rate of burning of pieces of the fuse whenever there is any doubt whatever as to its soundness. Although the manufacturers may produce a fuse with a regular rate of burning, the rate may be changed by bad handling, as, for instance, by squeezing the fuse in handling or tamping so as to disturb the powder core, or by suddenly and roughly opening the coil when it is stiff from cold, so as to crack the fuse; or the fuse may be injured by rubbing against the rough surfaces of the rock. In cutting the fuse and in fitting it into place, care must be taken that the powder core does not run out from the fuse, for that might cause a misfire.

Testing fuse.

Fuse injured by bad handling.

Care in cutting fuse.

Detonators (which are also called blasting caps, and sometimes are called exploders, though the last term applies to any means of producing an explosion, and therefore is not commended here) consist of copper capsules about as thick as an ordinary lead pencil, which are commonly charged with dry mercury fulminate or with a mixture of dry mercury fulminate and potassium chlorate that is compressed in the bottom of the capsule, filling it to about one-third of its length.

Detonators.

Dynamite and other detonating explosives are in practice fired by means of detonators, for though they may be exploded by the aid of squibs or fuse, or by means of gunpowder primers, yet the explosion so produced is not a complete one; the explosives are not used to their best advantage; all of the work that they can do is not done; and, moreover, the

Advantage in use of detonators.
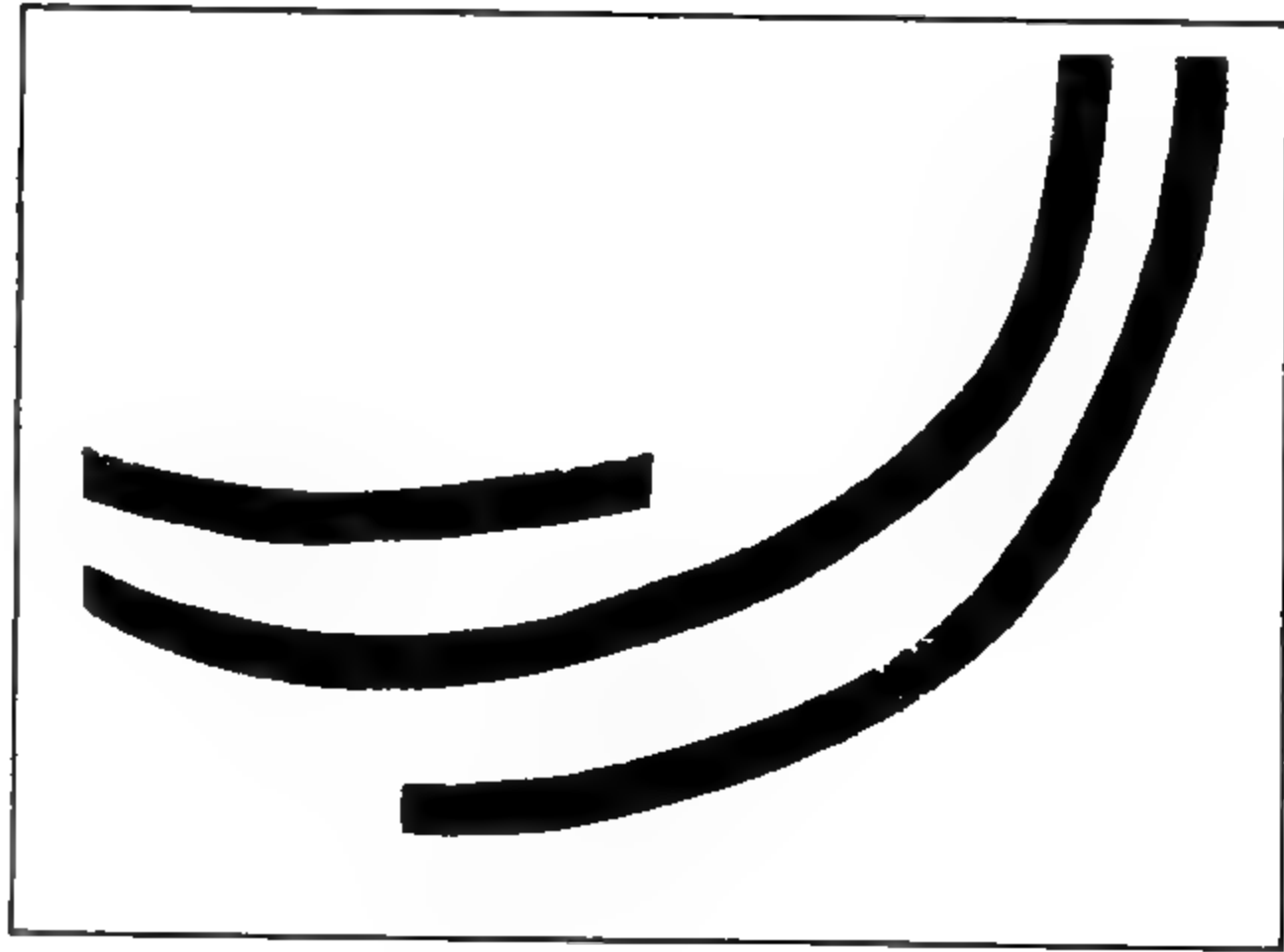
A   X-RAY PRINT OF DEFECTIVE FUSE.

B.   SIDE SPITTING OF A FUSE

gases that are produced are usually dangerous. Where high explosives are employed, it is safer to fire with detonators strong enough to cause their most complete explosion. Permissible explosives should be fired by detonators, and are best fired by electric detonators of the strength prescribed for each one. (See p. 67.)

Several grades of these detonators or blasting caps are to be found

Grades of detonators.

in the market, and they are differently designated by different manufacturers. The "strengths" of the detonators most commonly used, as measured by the weights of the fulminating composition contained in them, are as follows:

Grades of detonators and weight of their charges.

Testing-station grades.	Commercial grades.	Weight of charge in grams.	Weight of charge in grains.
No. 3	3X, or triple	0.54	8.3
No. 4	4X, or quadruple	0.65	10.0
No. 5	5X, or quintuple	0.80	12.3
No. 6	6X, or sextuple	1.00	15.4
No. 7	7X, or No. 20	1.50	23.1
No. 8	8X, or No. 30	2.00	30.9

Detonators are fired by the aid of a piece of fuse. The end of the fuse is inserted in the mouth of the blasting cap and

Attaching detonators to fuse.

carefully pushed down until it gently touches the surface of the detonating composition, and then the cap is crimped onto the fuse. (See Pl. IX, A.) The cap, with the attached fuse, is inserted in the charge to be fired, which, when placed in the bore hole and tamped, is ready for firing. The end of the fuse is lighted, and the fire burns down the powder core until it streams against the detonating composition, which then detonates and causes the detonation of the explosive with which it is in contact.

It has been found at the Pittsburg testing station that the flame which rushes out from a fuse when it is ignited at

Fuse not to be used in fiery mines.

the mouth of a bore hole will ignite an explosive mixture of mine gas and air. Even though a safety device is used to prevent spitting from the end of the fuse, flame may burst from the side (Pl. VIII, B). Therefore fuse should not be used, either alone or with detonators, in fiery mines.

The practice of fitting the fuse to the detonator is common in quarries, tunnels, and mines that are not gaseous.

Fuse and detonators must be of standard size.

Accordingly, it is customary to make both detonators and fuses in standard sizes, so that the fuse may easily slip down within the mouth of the detonator and yet make a neat fit within it.

By the use of electric detonators (also called electric fuses), the dangers that are common in the use of squibs or fuse in gaseous coal mines are avoided. (See Pl. IX, *B*, and fig. 3.) These electric detonators are simply ordinary detonators that have been fitted with a means of firing them by the electric current. This is done by inserting within them two copper wires, joined at the inner ends by an extremely fine platinum or other high-resistance wire, which, like the carbon filament in the ordinary incandescent lamp, becomes heated till it glows when an electric current is passed through it. This wire, known as the bridge, is placed above the detonating composition, and is surrounded by gun cotton or loose fulminate. The space above it and the mouth of the capsule are then filled and closed by means of a plug of sulphur or other waterproof composition, which is poured in while soft. The copper wires pass through the plug and are long enough to extend outside the capsule. These outer ends are called the legs or wires of the electric detonator. Although the copper wires are bare within the electric detonator, the legs outside are covered with an insulating wrapping. These legs are made of different lengths in order to suit different depths of bore holes. The charge of detonating composition differs in the different grades of electric detonators so as to give different strengths.

The following table gives the grade and weight of charge for the more common electric detonators:

Grades and weights of charge of electric detonators.

Testing-station grades.	Commercial grades.	Weight of charge in grams.	Weight of charge in grains.
No. 5.............	Single strength......	0.80	12.3
No. 6.............	Double strength.....	1.00	15.4
No. 7.............	Triple strength......	1.50	23.1
No. 8.............	Quadruple strength.	2.00	30.9

In loading bore holes electric detonators are placed in the charge just as detonators with fuse are, and the bore holes are tamped in a similar manner. To fire the charge, the legs of the detonator are connected by leading wires to an electric device at a safe distance, and from it the current is sent to fire the blast. No flame can escape from the bore hole during the firing, for the tamping fills the hole completely, and hence blasting in gaseous mines is made much safer.
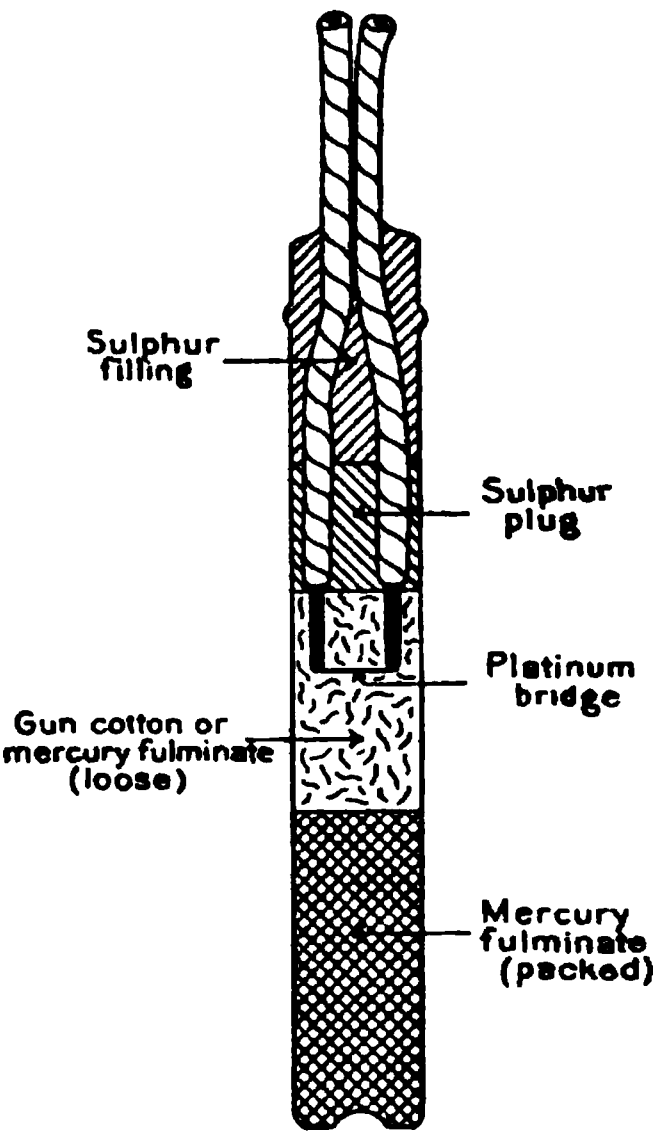
Sulphur filling

Sulphur plug

Platinum bridge

Gun cotton or mercury fulminate (loose)

Mercury fulminate (packed)

FIGURE 3.—Electric detonator, showing its component parts.

A. CRIMPING DETONATOR ON FUSE.

B. DETONATORS AND ELECTRIC DETONATORS.

Only electric detonators are used at the Pittsburg testing station in the tests of explosives for use in mines.

What are called delay-action electric "exploders" or detonators are now being offered for use where a number of holes are to be fired at once, but so that the charges may explode one after another. This is done by placing a piece of fuse or other device in the electric detonator between the detonating composition and the bridge and inclosing the whole so that the flame may not escape from the blast hole. In the present state of knowledge this practice is not commended for use in coal mines.

Delay-action electric detonators.

In the description of mercury fulminate attention was called to its extreme sensitiveness to heat, friction, or blows and to the extreme violence of the explosion which it undergoes. All these properties therefore belong to detonators and electric detonators, and these little devices should be treated with the utmost respect. Never attempt to pick out any of the composition. Do not drop them or strike them violently against any hard body. Do not lay them on the ground where they may be stepped on. Do not step on them. In crimping, take the greatest care not to squeeze the composition, and never crimp with the teeth, for there is enough composition in one of these small capsules to blow a man's head open. They should be stored in a dry place and in a building apart from any other explosives. They should never be carried into a mine with other explosives, and they should never be placed in a mine near other explosives except in bore holes. When carried or shipped, they should be packed firmly with a quantity of elastic material, such as felt or the coiled legs of the electric detonators, about them, and they should not be exposed to heat, blows, or shocks of any kind.

Danger in use of detonators.

MINING COAL WITH EXPLOSIVES.

No universal rule can be made for blasting coal, for the local conditions, the character of the bed, and the method *Conditions in coal mines.* of working make necessary the use of different means in different mines and sometimes even in different parts of the same mine. The best method of blasting in any given mine or part of a mine is determined by practical experience and observation.

The placing of bore holes, as well as the size of the charge, is of vital importance. In placing them special attention and due consideration should be given to the bedding and cleavage planes of the coal; also to slate and bone parting, horsebacks, clay slips, and other local irregularities.

In this country, apart from the not widely used long-wall system and from the pillar pulling or withdrawing, in both of *Shooting off the solid.* which little or no explosive is used, there are two general methods of bringing down coal in entry driving or room work, namely, "shooting off the solid" and undercutting or shearing before shooting.

In the coal mines of the middle interior fields, where shooting off the solid is largely practiced and where there are no marked faces or butts, the following method is used: A hole is bored or drilled in the face at or near the middle of the seam, at such a slant as to make a small angle with the face. If an imaginary line (AB in fig. 4) drawn from the back of the drill hole at right angles to the hole passes out of the open face, and if that distance is not too great, the hole is rated as "safe" by those who use the method. If, however, the hole extends beyond A to X (fig. 4), the extended part is said to be "dead" and the hole is considered "unsafe." A hole is also considered "unsafe" if the angle ACB is greater than 35°. In the softer coals and where the joints or cleavage planes (cleat) are favorable a greater angle is used, but no drill hole, even under such favorable conditions, is bored at an angle greater than 45°.

38

In shooting off the solid only one face of the coal to be thrown off is exposed. It must be torn off along the line AB and AC (fig. 4) and in addition must be forced out along the bedding planes at top and bottom. Where such bedding planes are smooth this is not difficult, but generally they are irregular, and a strong shearing force must be exerted parallel to the bedding planes, both at the top and bottom. This method to be effective requires a slow-acting explosive, and black blasting powder has been much used in the work.

Need of slow-acting explosives.

A second hole and even a third one is sometimes drilled and charged before the first one is fired, and these are called "dependent" shots. The fuses are sometimes made of different lengths and lighted at the same time, with the expectation that the shots will go off in the proper order. Such practice is now generally held to be very wrong even in "solid shooting" districts. The second and third holes should not be drilled until after the first shot has been made, so that the location of each shot can be properly judged.

Dependent shots.

The size or weight of the charge in shooting off the solid varies much in different coals. In fact, it is extremely difficult, even in the same coal, to judge the amount correctly each time.

Overcharging.

FIGURE 4.—Shooting off the solid.

If undercharged, the hole is likely to "blow out;" hence it follows that holes are almost invariably overcharged, and in some districts all sense of right proportion has been lost by the miners.

Aside from the dangers in the use of black powder, the uncertainties in proportioning the charge to the work are such that the method of shooting off the solid can not be approved as either precise or safe. Many of the great mine disasters of this country have undoubtedly started from misjudged or overcharged shots off the solid.

The other method of bringing down the coal in which the explosive is assisted by undercutting or shearing beforehand and which was early used in this country is now being readopted in most parts of the country. The object of undercutting or shearing is to expose two faces of the mass of the
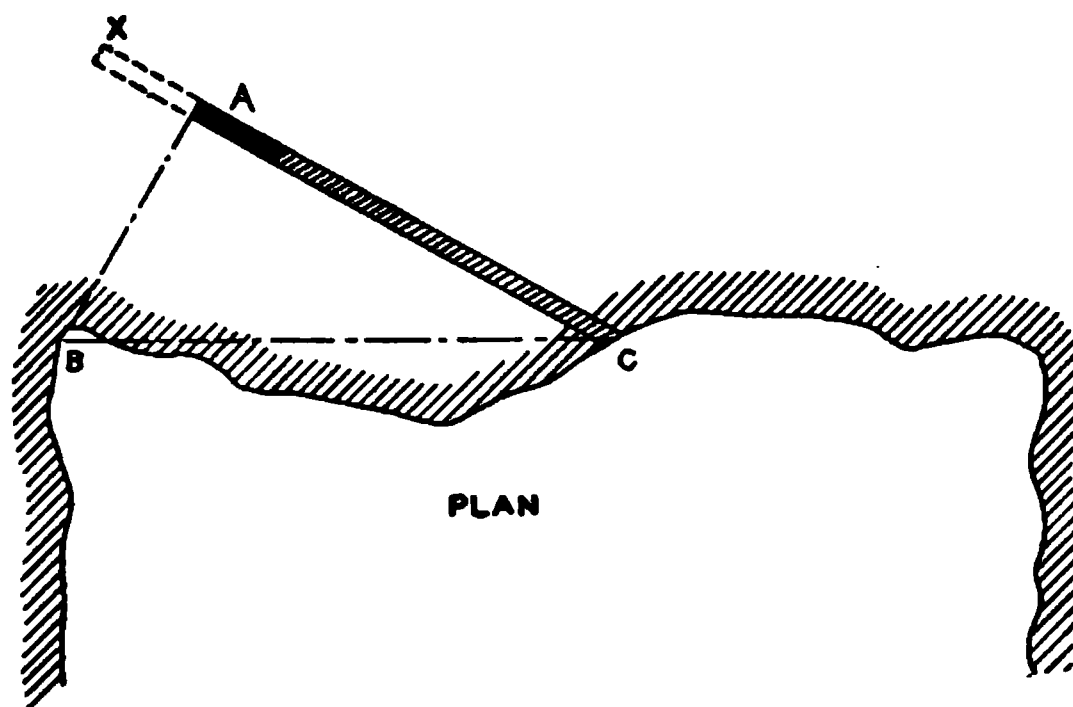
Undercutting and shearing.

coal to be brought down, and, as coal generally tends to break along vertical planes, to permit the explosive to exert a wedging effect, rather than to shear or tear off the mass as it must in shooting off the solid.

There are two ways of applying this method—shearing and undercutting. Occasionally, where the coal is hard to shoot down, both shearing and undercutting are done, so that a less amount of explosive is needed; in fact, in some places none is required, as the coal can be wedged down.

Where the cutting is by hand and the top and bottom part "freely," shearing is the easier, and is usually employed in entry or narrow work. In some cases the shear or vertical cut is made on but one rib, but generally it is made in the center of the narrow face and the shot is so placed as to throw the coal toward the shear.

Where the coal is all alike in character and

Shearing.

parts equally well at top and bottom, the hole is started at or near the middle of the seam and drilled nearly parallel with the

PLAN

FIGURE 5.—Shearing.

shearing, slanting a little upward to cross the bedding planes, and also to clear itself of dust as it is being drilled. The hole should never go deeper than the cutting, and it is better for it not to go as deep by at least 6 inches as the cutting. In figure 5 the back of the bore hole is shown as reaching the projected line of the rib, but in softer coals the backs of the bore holes are usually at least 6 inches from the projected line of the rib.

In districts where black powder is still used it is conceded that a shot hole of this character should never be charged with more than 2 pounds of black powder, and better with much less. It is difficult to make rules for an exact amount, because the

Charge of explosive in shearing. proper amount differs with the length of the hole and cutting, the strength of the coal, and the way that it parts from top and bottom. However, the work should never be so laid out that it will require more than 2 pounds of black powder. If one of the permissible explosives is used, the charge should be, in general, only about one-half (by weight) what would be required if black powder were used; but no work should be so laid out—that is,
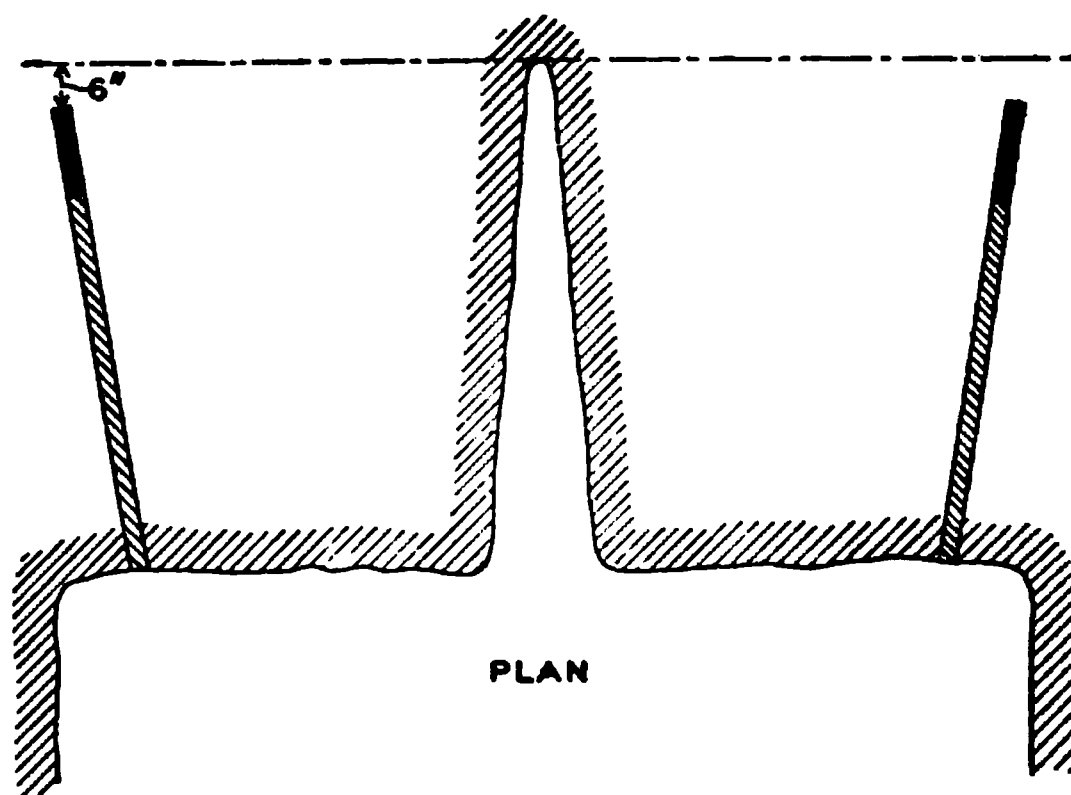
no drill hole should be so located with reference to the shearing—as to require more than a pound and a half of the explosive.

Where the place is so wide that another hole is required near the first, when the first has done its work properly a similar situation is left for the second hole.

Where the coal is undercut, either by hand or machine, the purpose of the shot is to bring down the mass of coal **Undercutting.** by wedging from above. In such a place the greater part of the force of the explosive used in the first shot will go to shear off the coal on both sides of the shot, the expanding gases from the explosive working along the bedding plane at the line of the drill hole and the mass pivoting at the back of the undercutting. The stronger the bedding of the coal—that is, the less marked the vertical planes—the more difficult is this shearing, which then becomes a tearing, rending effect at the sides of the mass, so that the shape of the mass is somewhat conical, the top being at the line of the drill hole and the base at the undercutting. Under the circum-

Floor

FIGURE 6.—Snubbing shot.

stances the coal above the drill hole generally does not come down, but it is usually so shattered that it may be pulled **Charge in undercutting.** down with a pick. Necessarily this first shot takes more explosive than later shots, but the amount should never be more than that already stated for the shearing method.

To help the first or "buster" shot, if the undercutting has been done by machine, it is advisable, and in some cases **Placing of the shots.** necessary, that the coal at the front edge of the undercutting be "snubbed" off either by the pick or by a small "pop" or "snubbing" shot (fig. 6). In narrow work, if the "buster" shot has done its work properly at one rib, the second shot is placed at the other rib. In wider work the "buster" shot is usually placed near the center of the room face and the second and third shots are placed on either side (fig. 7). Each of these is so placed as to throw down a mass of coal which practically has three faces free—the front, the bottom, and one end. The chief work of the shot is to wedge off the rib end and push away from the back. Such a shot usually only requires from one-half to three-quarters of a pound of one of the permissible explosives. The work should be adjusted to

these charges, so that if three shots besides the snubbing shot (if one
is needed) are not enough, four or even five shots
should be used. It is far safer to use a number of
shots with a small amount of explosives in each than
to use a few shots with a large amount; and on the whole less ex-
plosive will be needed in all the small shots than in the few large shots.

Advantage of small charges.

The depth of the undercutting varies with the character of the coal
and with the thickness of the seam, but in hand-pick
work the depth is not commonly greater than the
thickness of the seam. Where machines are used to
undercut, the depth is from 6 to 7 feet, depending on the machine.
With machines the cutting is usually done at the bottom of the seam;
if the seam is thin (less than 3 feet) the cutting is done in the under-
lying clay, if there is any. Where the undercutting is done by hand
pick. it is sometimes done in a soft layer near the middle of the seam,

Depth of under-cutting.

Roof

Floor

FIGURE 7.—First or "buster" shot.

or in a parting of soft clay, but so far as the placing of the shots is
concerned, the part above such an undercutting may be regarded as a
thin seam, the coal below the cutting being lifted afterward by
"heaving" shots. Generally the cutting is in the bottom, and where
it is the shots are usually placed above the middle of the coal and
sometimes near the top. Where the coal is undercut and black
blasting powder is used, owing to the powder's slow wedging action, the
exact position of the shot is not of such special importance as it is
where permissible explosives are used. As already explained, these
are quicker in action than black blasting powder, and unless they dis-
lodge the coal instantly their force is spent in shattering the coal near
the drill hole. Therefore with permissible explosives the mouth and
back of the drill hole should be nearer the roof and the hole should
slant upward in order that the back of the drill hole may reach the
top bedding plane (fig. 8). The break will then be clean and a
wedging action will be exerted along the top bedding plane.

In the use of permissible explosives, special care should be taken that each bore hole has the same width throughout

Care in using permissible explosives. and is wide enough to permit the cartridges to pass through it without too hard ramming. Too small a hole may cause the cartridge to stick, and nitroglycerin explosives or even black powder may be exploded by the friction of the tamping bar against the sides of the hole. Daily attention should be given to the drills that are used in drilling the bore holes, and the points of the bits when being sharpened should be made to a standard size.

Before a shot is fired in a working place "bug" dust and all other coal dust should be thoroughly wet and sent out of

Dust must be wet down and removed. the working place. No cause of explosions has been more common than the presence of coal dust when shots are being fired. If the working place is naturally dry, it should be thoroughly sprinkled, and all the ribs, roof, and props within 40 feet of the shot washed down by hose before shots are fired.

Good results have been obtained in bituminous coal mines during the winter months by warming and moistening

Humidifying mines. the air entering the mine by means of exhaust steam and spraying devices. In experiments made in December, 1908, at the Pittsburg testing station the outside air entering the gallery

FIGURE 8.—Bore hole for permissible explosives.

was warmed up to a mine temperature and moistened by drawing it through humidifiers. It was found that if the air is kept at a relative humidity of 90 per cent and a temperature of 60° F. for 48 hours, thus giving conditions like those of summer in a mine, the taking up of moisture by the dust and the blanketing effect of the moist air prevent a general ignition of the dust by a blown-out shot of black powder.

Since the new permissible explosives began to be used it has been

Shot firers. found that more satisfactory results are obtained in mines where the loading and tamping of all shots are done by a few competent men known as "shot firers."

For the greatest safety the loading and firing of all shots should be done by shot firers after all other men have left the mine. The
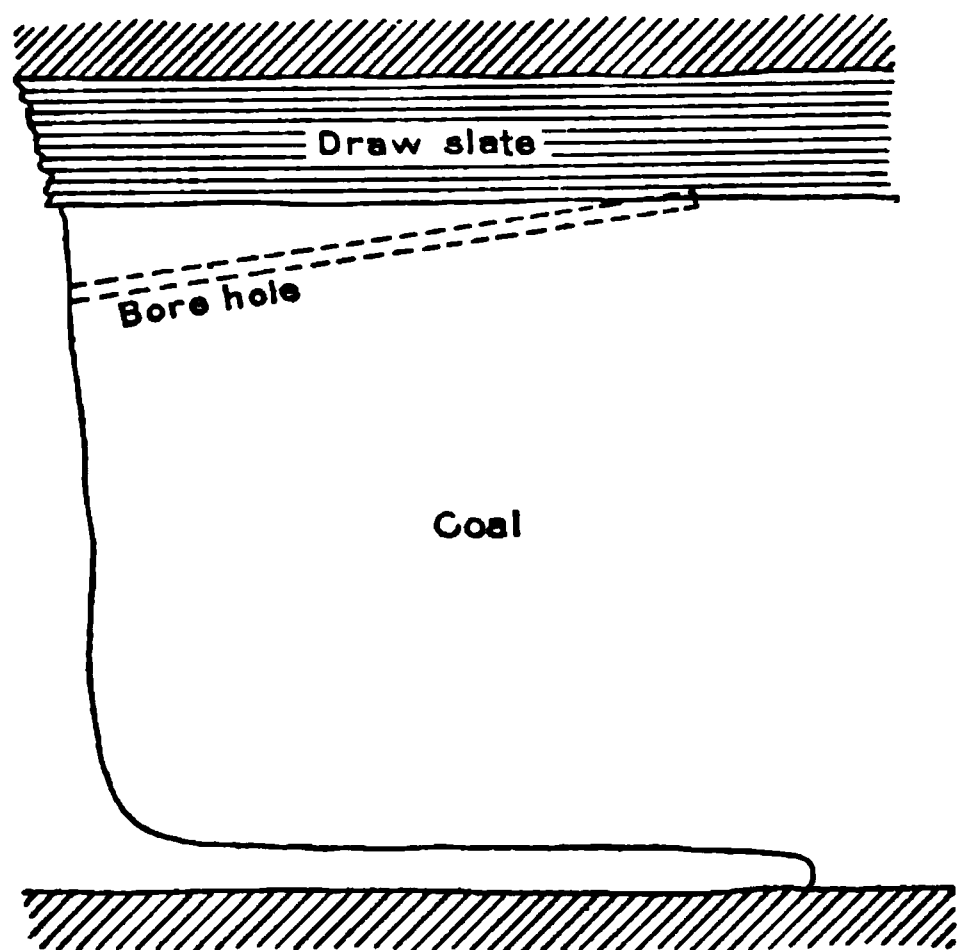
practice of having all shots loaded and fired by shot firers during the shift, which has lately been introduced in some of the mines of the Pittsburg district, is certainly a step in the right direction.

It is plain that the greatest safety and best work can not be obtained when the miners are allowed to load and fire their shots, because the new permissible explosives must be properly handled to get the desired results. The shot firers should be selected from the more intelligent miners, and they should be thoroughly instructed in the great dangers that arise when the permissible explosives are used in any other manner than that specified by the Pittsburg testing station.

LOADING AND FIRING CHARGES OF EXPLOSIVES.

In blasting, any explosive gives the greatest disruptive effect when the charge most completely fills the borehole **Loading bore holes.** from side to side. If the explosives are supplied in cartridge form this condition can often be obtained in the bore hole by splitting the wrapper, gently pushing a cartridge down into place in the bore hole with a tamping stick, gently squeezing it so that it spreads out to fill the entire width of the hole, and repeating this with each cartridge until the charge has all been put in. Finally, the detonator is placed in the last cartridge put **Primer.** in, and this cartridge is known as the primer. The primer is gently pushed down into place in firm contact with the remainder of the charge, and the hole is tamped (fig. 9).
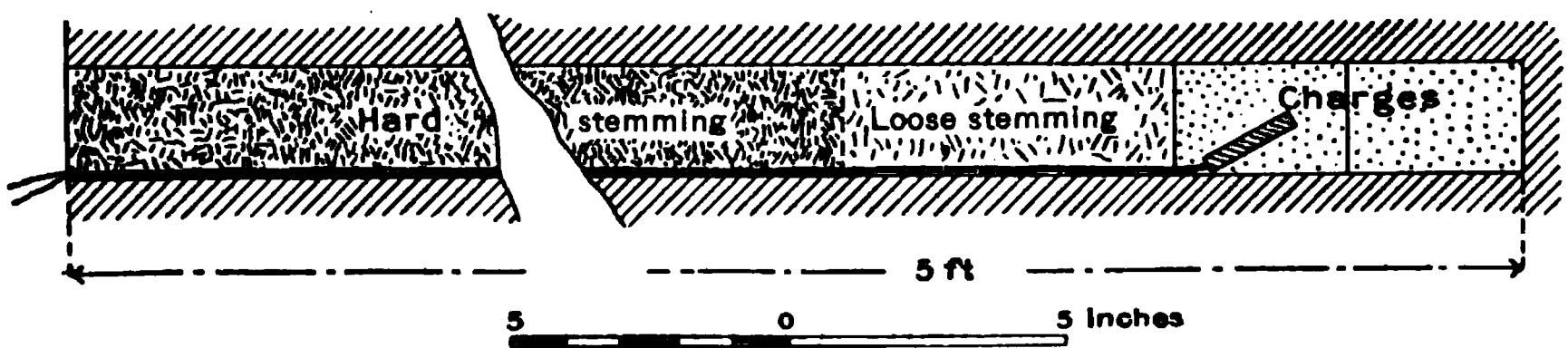

FIGURE 9.—Bore hole ready for firing.

If the same weights of different explosives are of equal strength, the one that takes up least space—that is, the densest— **Density of charge.** will have the greatest effect in breaking coal or rock. Of two cartridges of equal size containing different explosives the heavier cartridge is said to have the greater density.

Black blasting powder to be used in blasting is made up into a cartridge by means of a paper wrapper which has **Loading black blasting powder.** been formed about the handle of a pick. When this cartridge has been charged with powder, the electric igniter or fuse is placed and well fastened, and the cartridge should then be gently pushed down into the bore hole by means of a wooden tamping stick, which is safer than any metal bar. **Tamping stick.** An iron tamping bar should never be used. When squibs are used, the cartridge of powder is placed in the bore hole and then the stemming [a] is put in about a copper or brass needle

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[a] In this bulletin and in other publications of the Bureau of Mines, the material packed on a charge in a bore hole is termed "stemming"; the act of packing or ramming the material is termed "tamping."

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rod until the hole is filled. Then the copper needle is withdrawn and the squib is put through the opening.

When only fuse is used, it should be long enough to reach beyond the mouth of the bore hole. The stemming should be packed in about the fuse quite to the mouth of the bore hole, and the fuse should be completely surrounded by tamping.

Placing fuse and tamping.

It is observed that in some mines the practice has been to use but a short length of fuse and to let the charge explode untamped, or simply secured by running the tamping bar into the hole. This is a very bad and dangerous practice and should be forbidden.

Danger of firing untamped holes.

When detonators are used together with a fuse, the fuse should be cut off squarely at the end, gently inserted within the detonator until the powder core touches the detonating composition, and then, with the fuse held in the left hand, the detonator should be crimped onto the fuse with crimpers close to the open end of the cap, so as to make a perfectly tight and secure joint, care being taken in crimping that no pressure is brought to bear upon the detonating composition.

Fitting fuse in detonator.

Two ways are in use of inserting the detonator and attached fuse into the stick of explosive that goes on top of the charge and is known as the primer. The more approved way is to open the top of the cartridge or stick of explosive by unfolding the paper at the end; then to make a hole by means of a wooden skewer or lead pencil in the top of the cartridge, deep enough to let the detonator be pushed into it up to the line of crimping; then to gather the end of the paper jacket or envelope together about the fuse, the whole being bound with twine, so as to fasten the detonator and fuse firmly in place.

Fitting fuse and detonator in primer.

Another way that is sometimes used is to insert the wooden skewer into the side near the upper end of the priming cartridge so as to make a slanting hole in the charge deep enough to take the detonator up to the crimping mark, then to insert the detonator and bind it and the fuse close to the cartridge with twine. (See Pl. IX, A.)

The first way is perhaps more generally used, and it is better where the cartridge fits neatly into the bore hole. When the second way is used, the bore hole must be larger, as there should be some leeway between the cartridge and the side of the hole. In either way, when the primer, with the detonator and fuse, is put into the bore hole, extreme care should be taken that they do not come apart, for if there is any space between the cartridges in a charge, or particularly

Be careful not to pull detonator out of primer.

between the detonator and the explosive in the priming cartridge, the explosion may be prevented altogether, or may

Detonator must not be completely buried. be a very poor one. Likewise, when a fuse and detonator are used in loading, care should be taken that the detonator is not completely buried in the explosive, for as the fuse burns and fire rushes from its end some of it may blow out over the top of the detonator and set fire to the explosive about it before the detonator is set off. This has been a common cause of inferior and dangerous explosions.

The same sort of trouble happens if coal dust or any other dirt is allowed to get between the cartridges in a charge,

Dirt between cartridges. or between the priming cartridge and the charge. In loading, extreme care should be taken to make sure that the cartridges all touch one another closely.

When electric detonators are used they are fastened in the priming cartridge in ways like those described above for det-

Fastening electric detonators. onators used with fuse. When the electric detonator is inserted in a hole in the side of the priming cartridge, the practice has sometimes been to fasten it firmly by taking a half hitch around the priming cartridge with the legs of the detonator, the loading and tamping being then done as already described. This last means of attaching the electric detonator to the priming cartridge is not a good one, because the legs are likely to become kinked, and also because there is a chance that when the priming cartridge is pushed into place the insulation may be rubbed off from the legs and the wires may be short-circuited.

Although it has been stated that with certain explosive, which are somewhat largely used, the cartridge case may

Some explosives, if split and tightly packed, may not explode. be split and the charge rammed firmly into place, this is not the universal practice and should not be done with all the ammonium-nitrate class of explosives (p. 21), nor with some of the nitro-substitution explosives, for if they are tightly rammed in the bore hole it is difficult or even almost impossible to explode them.

After the priming charge with its fuse and detonator or its electric detonator has been inserted in the bore hole, the hole should be tamped with clay or with other material that can not burn. It

Instructions for tamping. should never be tamped with coal dust (either wet or dry) or with machine cuttings, known as "bug dust." The tamping should be done by means of a wooden tamping stick. The pressure in tamping should be very gentle on the first tamping material put in, particularly if detonators are used in the primers, and great care should be taken at this time not to

disturb the position of the detonator in the primer. Special care should be taken not to draw the detonator out from the primer or the fuse out from the detonator. When fuse is used, care should also be taken not to rub its surface off.

After the first 6 inches of the stemming material has been pressed down, greater force may be used in ramming the rest, because the firmer the stemming is the better is the woik of the explosive and the less is the chance of a blown-out shot. The stemming should be continued quite up to the mouth of the bore hole. If fuse has been used, the upper side of it near the end may now be cut into on a slant, with a sharp knife, and the outer part bent away so as to form a notch in which the powder from the core gathers and to which the igniter is applied. This cutting prevents the loss of powder from the fuse and makes it easier to light.

Air spacing of charge to reduce shattering effect. The shattering effect of high explosives may be lessened in loading simply by pushing the cartridges into place without splitting or afterward squeezing them, so that an air space will be left about the cartridges in the bore hole, and then proceeding with the priming and tamping. This air space notably lessens the shattering effect of the explosive (fig. 10).
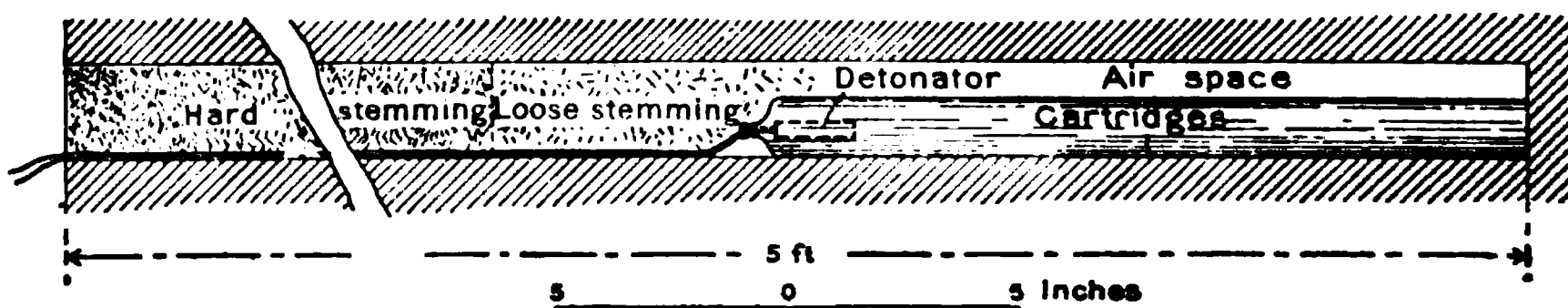

FIGURE 10.—Loaded bore hole showing air space about the charge.

Electric igniter. Where it is desired to use black blasting powder, electric black-powder igniters, sometimes called electric safety fuses or squibs, are recommended for setting off shots. They are made in a general way like electric detonators, but gunpowder or other slow-burning composition is used in them instead of detonating composition. They are much safer for use in coal mines than ordinary squibs or fuse, both because they do not throw fire into the mine air and because they permit better tamping of the bore holes.

Instantaneous fuse. It sometimes happens that it is desired to fire a number of charges at the same instant. This is readily done with electric detonators by coupling them up in series from hole to hole and firing by one discharge from the machine. This method endangers the roof and may cause falls. In mines other than coal mines it may be done by instantaneous fuse running from a central fuse to the several charges, but this practice is not a good one in coal mines, because the fuse may set fire to any dust or gas that is present.

In coal mines it is more commonly desired to fire one or more of the charges before the other charges, and this may
Delay-action detonators. be done in a single act of firing by the use of the delay-action electric detonators already described (p. 37). An ordinary electric detonator is placed in the charge for the central breaking-down shot, and delay-action electric detonators are placed in the charges for the right and left rib shots. This method of firing has many advantages over the methods of firing successive shots by means of different lengths of running fuse, but neither method is recommended for use in gassy or dusty coal mines.

The safest way is to fire but one shot at a time, and to allow time
Safety in single shots—Time between them. enough between shots for the ventilating current to mix with and render harmless the products of combustion from the previous shot and to carry off any coal dust that may have been thrown into the air by the shock of the previous shot. The interval of time that should elapse between shots differs with local conditions and the amount of ventilation, but in ordinary mining practice the interval should never be less than five minutes for shots made in the same working place.

In the making up of charges for loading bore holes and during
Danger from flame and sparks. the loading, extreme care should be taken that the explosives are not exposed to the flames from naked lamps or to sparks from the striking of metals upon each other or upon rocks, or from any source, since any of these may cause serious accidents.

As already suggested, the right size for a charge of explosive for blasting in a coal mine can be found better by practice
Failure of formulas for size of charges. than by theory. Several formulas have been devised by which to determine the right charge beforehand, but unfortunately they have not given satisfactory results in practice. If the material or mass to be blasted were always alike throughout and of equal hardness, theoretical rules could be made to apply, but such is not the fact. Differences in the resistance of the material to be blasted and in the rate of burning or detonation and the breaking force of the different explosives all affect the results of a blast.

Thus, for instance, in soft bituminous coal a permissible explosive containing only 20 per cent of nitroglycerin has
Comparison of effects of different explosives. been found to bring down more coal, and better coal, than one made under a similar formula but containing 25 per cent of nitroglycerin. A very quick explosive should not be used in bituminous coal mines where lump coal is sought. For instance, 40 per cent dynamite, which

has been found by experiment at the Pittsburg testing station to have a rate of detonation of 4,688 meters (15,380 feet) per second, is unsuitable for producing lump coal; but the permissible explosives that have rates of detonation between 1,866 and 3,617 meters (6,122 and 11,867 feet) per second are found to be well adapted for this work. Explosives that develop very high pressures are also unsuited for this work. Thus the 40 per cent dynamite referred to above has been found to produce a pressure of 8,308 kilograms per square centimeter (118,165 pounds per square inch), but the permissible explosives show pressures as low as 4,833 kilograms per square centimeter (68,740 pounds per square inch).

In deciding on the charge of a permissible explosive for use in a coal mine it is safe practice to use about one-half the weight of black blasting powder that would be needed to do the work; but no charge of permissible explosives should be more than 1½ pounds. As stated before (p. 42), bore holes for permissible explosives are placed by a different rule for depth and direction than that which is followed when black powder is used. No permissible explosives nor any high explosive should ever be used in the same bore hole with black blasting powder.

Size of charge of permissible explo- sives for coal mines.

The most obvious objections to overloading are that it crushes and wastes the coal, and that it throws fire and flame out into the air of the mine. Another objection is that the surplus force of the shot may so weaken the roof and surroundings as to cause falls, which may not occur, however, for some time after the shot has been fired.

Objections to overloading.

Underloading, on the other hand, not only causes loss and waste, but it may so fissure the coal near by as to make it dangerous to fire another shot near the place. At the same time it may happen that the underloaded charge, though not strong enough to bring down the coal, may spring the bore hole, throw out the tamping, and give a blown-out shot; that is, a charge that is not heavy enough to make a blast may be heavy enough to act in a bore hole as it would in the barrel of a gun; and this may happen particularly if the tamping is not well secured and firm. Blown-out shots are especially to be feared in dusty and gassy mines, because it has been found that explosive mixtures, such as are present in such mines, are most sure to catch fire and burn most completely when a mass of flame, and more particularly a mass of glowing solid particles, is thrown into their midst. Investigation has shown that the larger number of the recent disasters in coal mines have been due to blown-out shots.

Objections to underloading.

Premature explosions, misfires, and hangfires are most likely to happen when squibs and fuses are used to set off charges, owing to defects that may be in these devices from the first, or may be caused in the handling, carrying, or loading of them. Miners are especially warned in case of a hangfire to avoid returning to the breast until half an hour has passed. Hangfires rarely happen with electric detonators, but it is possible that they may happen more often with delay-action detonators.

Premature explosions, misfires, and hangfires.

Keep away from a hangfire for half an hour.

Incomplete explosions may result from several causes. They may be due to failure to push in all the cartridges of a charge till they touch one another, thus leaving an air space between them, or else a mass of coal dust or dirt, which breaks the path of the detonation from cartridge to cartridge. They may be due to the pulling out, even but a little way, of the detonator from the primer or of the fuse from the detonator. In the use of nitrate of ammonia or nitro-substitution powders incomplete explosions may be due to too tight packing and compressing in the bore hole. In any case, a partial explosion is a marked source of danger; first, because it may have the effects of an underloaded charge; second, because the unexploded part of the charge may burn and throw out flame and sparks into the mine, and also give out poisonous gases and fumes; third, because the unexploded part of the charge, if it is not burned up, may be brought down with the coal and give rise to an accident in the breaker, or, if it passes the breaker, to an accident in the transportation or the use of the coal. Whenever there is a partial explosion, if coal has been brought down, careful search should be made in the coal for the remainder of the charge.

Partial explosions.

In case of a misfire no attempt should be made to draw the charge, but a new bore hole should be placed at least 2 feet away from the first one and fired, and after the coal has been brought down it should be carefully looked over to find any unexploded material that may have come from the hole that misfired. When a hole charged with black blasting powder has misfired, the stemming and charge may be withdrawn, drenching them with water while withdrawing them. After the hole has been dried out it may be reloaded.

FIRING BLASTS BY ELECTRICITY.

The methods used in causing the explosion of charges in blasting depend on the nature of the explosive. To cause the **Danger of firing by flame.** explosion of an explosive of the black-powder class, it is only necessary to put a flame to it, but a violent shock is necessary to cause the detonation of high explosives so that they will have their greatest breaking effect. As already stated, black-powder charges are set off by means of squibs, fuse, or electric igniters. Squibs and fuse are set on fire by means of the flame of the miner's lamp, or sometimes by heating a wire to the glowing point in the miner's lamp and applying it to the match of the squib or the cut end of the running fuse; but evidently these methods would be dangerous in fiery coal mines, and hence they should never be used in such mines.

An electric igniter or an electric detonator should be so loaded into a bore hole that while it is in perfect contact with the charge the legs of it reach at least 6 inches out of the completely tamped hole. Both legs should be bared of their insulation for about 2 inches from their ends, and the wires scraped bright so that a good **Connecting legs to leading wires.** electrical contact can be made with them. Each leg is then firmly connected with one of the leading wires by about five turns. It is bad practice to have the two splices directly opposite each other, because when the leading wires **Splices should not be opposite—Wrapping splices.** are pulled the splices may touch one another and thus make a short circuit, which will prevent the electric igniter or electric detonator from being exploded. A better plan is to wrap the bare wire splices with tape made for the purpose, which will completely insulate them.

After the legs are spliced to the leading wires (and only after), the wires are connected to the firing machine from which **Connecting leading wires to firing machine.** the electric current is to be obtained. This last connection should never be made until all the men are at a safe distance from the place where the blast is to be fired. The rule should be made and never broken that when bore holes are charged the connecting up shall move from **All connections to be made from bore hole to firing machine.** the bore hole back to the firing machine. The work in the mine should so organized that it can never be possible for the leading wires to be coupled up to the firing machine while anyone is about the place where the holes are being charged and where the blast is to be fired. In heavy blasts

in development work, two or more electric detonators may be used to good advantage in the same bore hole. For this purpose they are connected up in series, which means, for two detonators, that a leg of each is bared and the two legs twisted together and wrapped with insulating tape, and that then the two free legs are attached to the leading wires, just as where but a single detonator is used. In coal mining the charge used should never be so large as to require the use of more than one detonator in the same hole.

Connecting detonators in series.

When it is desired to fire two or more holes at the same time the detonators for these holes should also be connected up in series, and to bridge the space between the holes a cheap insulated wire, known as connecting wire, which is not as heavy as the leading wires, may be used. In coupling up a series of holes for this purpose, one leg of the detonator is connected to one leg of the detonator in the next hole, and so on to the last hole. There is then left one free leg in the first hole and one free leg in the last hole, and these are spliced to the leading wires. The usual precautions should be taken to wrap all the splices with insulating tape, so as to completely insulate them, and thereby insure a good circuit through which the current may pass. It should be borne in mind that the greater the number of holes to be fired in a single blast the greater is the necessity for making sure that the circuit is complete throughout, because if there is a break or a short circuit at any point, the blast will probably fail to fire. The delay, expense, and danger caused by such a failure can be prevented by giving careful attention in the first place to the charging and the wiring.

Connecting holes.

Danger from a break or short circuit.

The electric current for use in firing electric igniters or electric detonators may be obtained either from primary batteries, such as dry-cell batteries, or from secondary batteries, such as storage batteries, or from electric-lighting circuits, or from generators known as electric firing machines. (See Pl. IX, B.)

Sources of current.

Firing charges of explosives by means of ordinary dry cells has been prohibited in foreign countries, because premature firing of detonators, and sometimes of the charge, has been caused by the wires coming into contact with the poles of the batteries. Safety-contact dry-cell batteries have lately been introduced abroad and in this country. These are made with a spring-key contact, or with two safety-spring contact buttons, which are the poles of the battery. The two leading wires are laid on the buttons, which are at the same time pushed downward. When the pressure of the thumbs is released the contact is broken. If the wires of a detonator accidentally come into contact with the poles of the battery, the current can not be discharged unless both poles are pushed downward.

Dry cells.

Dry cells, small batteries, and some firing machines can be carried about by the miner who is to act as shot firer, and this is an advantage that insures him against premature firing by any other person.

Portable devices. Such small devices can at best be used with only a few shots in one circuit. The number of shots to be fired and the length of leading wires and other conductors through which the firing is to be done must be known beforehand, so that a battery of sufficient capacity can be selected. Batteries often fail to fire blasts because they can not send such a current as will fire through the great length of leading wires, connectors, and detonator legs that is used for the blast. A simple way to test the strength

Testing strength of batteries. of the batteries is to pass the current through a small electric lamp of known capacity and note the brightness of the light given by the lamp. Another way is to pass the current from the battery through a testing circuit whose resistance is equal to that of the circuit of a blast and which has in it one electric detonator. If the battery fires this detonator (which should be put in a safe place) it is strong enough and is in good condition. (See Pl. IX, C.)

When the electric current for firing is obtained from an electric-lighting circuit the connections are usually made in

Firing from electric-lighting circuit. parallel; that is, one leg of every detonator is connected to one of the leading wires and all the other legs to the other leading wire. Care must be taken, by the use of insulating tape, that there shall be no short-circuiting

**Connecting up in parallel.** in these connections. This method has the advantage that if there is a defective electric igniter or electric detonator in the circuit its failure will not prevent the rest of the blast from being fired; but, on the other hand, this method is objectionable because at any time after the explosion of the good igniters or detonators the unexploded charge with the defective igniter or detonator may be blown out and scattered in the coal, or it may even be set afire or perhaps exploded in the air of the mine by shock or friction. Further-

Premature electric firing. more, in this and other methods of electric firing an accidental premature blast may possibly be caused by leakage from the electric main to the earth and through the leading wires or connections, which may have become bared by rough handling or may not have been properly covered by the insulating tape. Premature explosions have been known to occur that were caused by leakage due to defective insulation.

Firing machines, sometimes called blasting machines, generate the electric current to be used in firing by mechan-

Dynamo-electric machines. ical means. A variety of such machines have been invented, but the two best-known classes are the dynamo-electric machines and the magnetos. The dynamo-electric
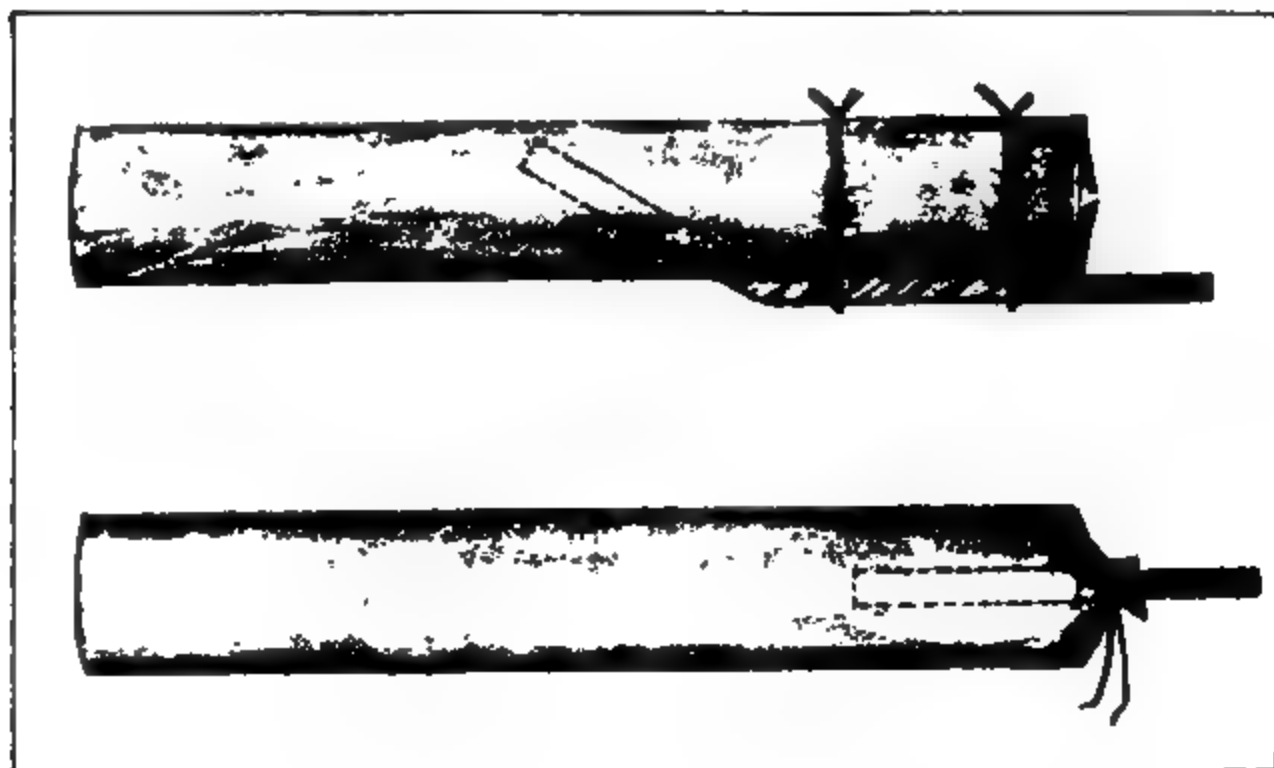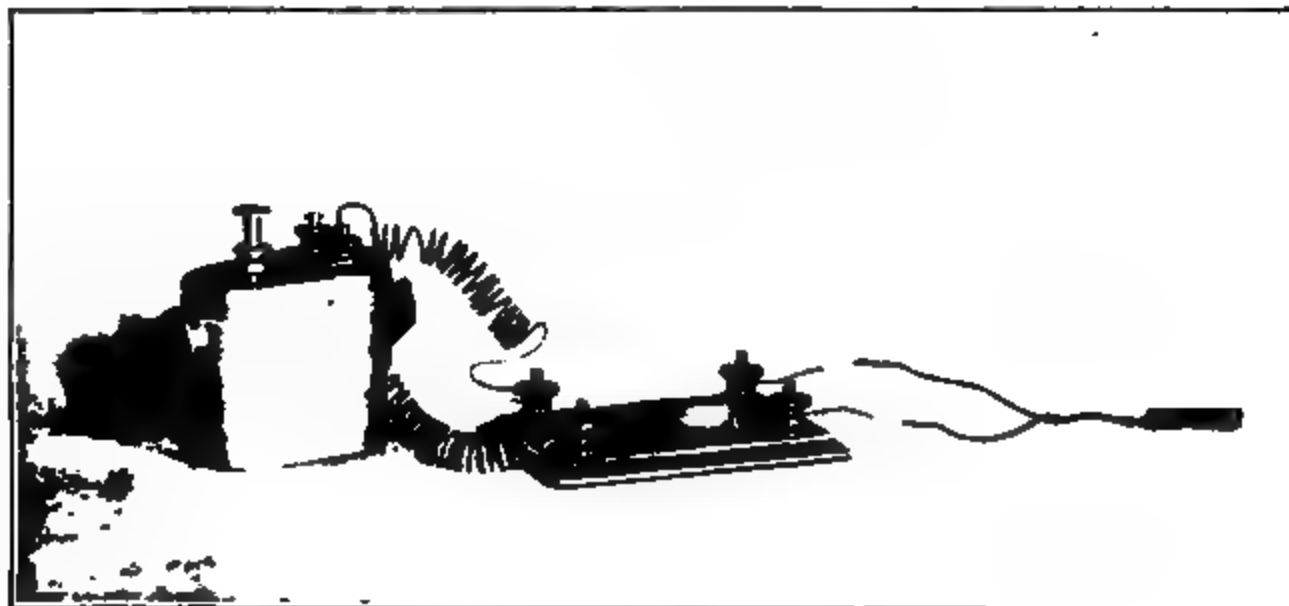
A. FUSE AND DETONATOR FITTED INTO PRIMER.
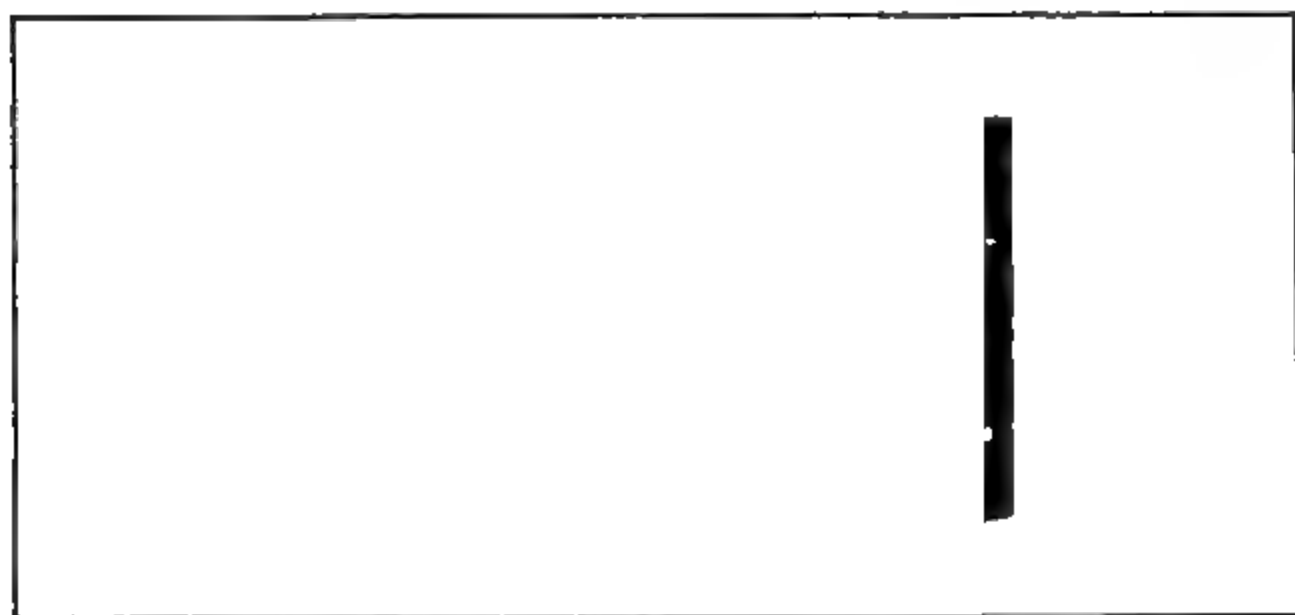
B. SECONDARY BATTERY, FIRING MACHINE, AND DRY CELL.

C. TESTING FIRING MACHINES AND BATTERIES.

machines are made like ordinary dynamos used for generating electric currents, differing only in that they are worked by hand. They contain a coil-wound armature which is rotated between the poles of an electromagnet. This armature can be made to revolve by means of a crank or a vertical ratchet geared direct to the spindle of the armature. The machines with ratchet bars are made so as to store up the current during a stroke, until just as the stroke is ended the entire current that has gathered is discharged through the leading wires.

Rating of dynamo-electric machines. These machines are built in different sizes and are rated according to the number of electric detonators they can fire. Thus, a "50-hole" machine will, when properly worked, fire 50 detonators at one discharge. The machines usually built for use in coal mines are rated as "4-hole" machines, and such a machine can be conveniently carried about by the miner or shot firer.

Magnetos. The magneto machines consist mainly of an armature revolving between the poles of a set of permanent magnets. They look much like the dynamo-electric machines that are worked by cranks, and they are used in much the same way. These magneto machines are used to a considerable extent in foreign countries, but the "push down" dynamo-electric machine is the one most commonly used in the United States.

Leading wires. The leading wires that carry the current from the blasting machine to the blast hole are of insulated copper wire, copper being used because it is one of the best conductors of electricity known and has the further advantage of being but little corroded in damp mines. These leading wires or firing lines are insulated with a braided covering, which is better if made waterproof. In some instances the two wires are twisted together and wrapped with an additional coating of braid, making them into one cable, which has the advantage of being more easily handled than two separate leading wires, and has also the advantage of the added protection given by the additional braiding.

Inspection and repair of leading wires after firing. After the blast has been fired, the ends of the leading wires should be immediately disconnected from the posts of the firing machine, and the lines should be examined for their whole length in order to see that the insulation has not been broken by coal or rock thrown against it, nor been stripped by the force of the blast. Where such defects or injuries are found, they should at once be repaired with insulating tape, and then the leading wires should be placed where they are not liable to injury until they are again needed.

For testing the line after it is connected up, and before the firing, in order to show that the circuit is complete and that there is no leakage in the wires, a special galvanometer may be used, together with a battery such as many of the manufacturers of explosives now sell. This galvanometer, like others, bears upon its face a needle, which is turned or deflected if an electric current is present. By noting whether this needle is deflected or not one can tell whether the circuit is closed or open, and the extent of the deflection shows just how little resistance there is in the circuit. To use the galvanometer, the wires leading from it are connected to the two binding posts of the firing machine, to which the wires leading to the charge have already been connected. The deflection may then be noted. The current generated by the very weak battery cell attached to the galvanometer should not be strong enough to fire the electric detonators used in the bore holes, but is enough to deflect the galvanometer needle. This testing galvanometer, with its attached battery, should never be applied directly to the face to be blasted, even when it is being used to find out, when the test has shown no current, which of the electric igniters or electric detonators are defective. The tests for the separate detonators or igniters should always be made through leading wires long enough to let the person making the test stand where he would be perfectly safe if the blast should be fired; and on no account should this testing of the igniters or detonators be made while any person is so near that he may be in danger from the blast.

Testing the line.

Use of galvanometer.

Safety precautions to be taken.

EXPLOSIVES IN SINKING SHAFTS AND BLASTING ROCK AND DIRT.

The use of any explosives other than permissible explosives is not recommended in any coal mine or part of a coal mine

Difference in conditions. except in early development work, such as shaft sinking or entry driving through rock strata. In such work all men should be out of the shaft or working place when shots are fired.

After the coal has been reached and it has become necessary that shots shall be fired while men are in the mine, permissible explosives only should be used. After a mine has been opened up, if rock or dirt is encountered, which may happen because of a fault or some other cause, it is quite necessary that permissible explosives be used, for it is known that inflammable gas is likely to be found in such places.

In the sinking of shafts or in the removal of rock or dirt by means of explosives, the methods to be followed in loading,

Loading, tamping, and firing. tamping, and firing the charges of explosives are similar to those described for use in blasting coal. In this, as in other work, electric firing will be found to be the safest means of shot firing, and in the long run the cheapest.

It is not uncommon to hear the statement that high explosives, because they are quicker in action than low explo-

Tamping high explosives. sives, need not be tamped. This is a serious error. The fallacy of it has been repeatedly proved in the tests of many different explosives made at the Pittsburg testing station. It has there been clearly shown that the highest pressure an explosive can give, and therefore the greatest amount of energy it can set free, will be developed only when the explosive is confined in the smallest possible space. Hence after the charges have been loaded into the bore holes they should be tamped with such materials (the best being damp clay) as confine the charges most closely, and this material should be rammed in firmly, with the precautions already set forth, quite to the mouth of the bore hole.

In the appendix setting forth the test requirements for permissible explosives (p. 68) it is stated that electric or other

Proper strength of detonators. detonators containing not less than 1 gram of the fulminating composition should be used in firing the charges. For use with high explosives in rock blasting, detonators of that strength are also best. Under no circumstances should an electric or other detonator be used of less strength than No. 5, con-

taining 0.8 gram of the fulminating composition. The greater efficiency and certainty of the stronger detonator more than make up for its slightly greater cost.

In the sinking of shafts, after the soil has been removed and the overlying layers of shale and rock are uncovered, it becomes necessary to use explosives; and because in such a place the ventilation is always poor and the miner must wait for the fumes and smoke to clear away after each blast before he can safely return to his work,

Firing shots in groups. time can usually be saved by firing shots in groups instead of singly. Dynamite, or, when the shaft is wet, gelatin dynamite, may be used for these shots, which should always be fired after the men are out of the shaft. The most economical and safest way of firing a number of shots at one time is by means of the electric current, with electric detonators. The older method of firing by fuse is dangerous and wasteful. Where fuse is used, there is always danger that a seeming misfire may prove to be a hang fire—that is, the smoldering fuse may cause the charge to explode unexpectedly. Also, if by any chance there is any irregularity in the burning of the fuse, the miner can not properly judge the time necessary to get out of the shaft and out of danger after having lighted the fuse.

In shafts that run through rock, as most shafts do, there is no objection to the shattering effect of firing several shots at the same instant, and this method is recommended; but when it happens that in shaft

Firing simultaneously.

sinking the shattering effect would be harmful, and successive shots are therefore to be used, it is still advised that they be fired by electricity. For such shots, however, a less violent explosive may be employed, and the delay-action electric detonator already described (p. 33) may be used to good advantage.

The following explosives may be recommended, in a general way, for use when the size and condition of the material resulting from the blast is not important, for example, in the sinking of shafts or the driving of entries through rock:

For use where the texture of the material is very tough and hard as in tough granite, hard bowlders, and the like, 60 per cent straight nitroglycerin dynamite is recommended. Where the material is of moderate toughness

Various explosives for use in sinking shafts and driving entries.

and somewhat brittle, 50 per cent straight nitroglycerin dynamite is recommended. In material such as limestone and sandstone, 40 per cent straight nitroglycerin dynamite is recommended. In hard earth or compact sand, a 30 to 20 per cent straight nitroglycerin dynamite is recommended. In material such as a soft crumbly or seamy rock that requires a stronger explosive than black blasting powder but a slower explosive than dynamite, a granulated

powder containing 5 per cent of nitroglycerin is recommended. This should always be fired with a priming stick of dynamite. With this exception, different kinds of explosives should never be used in the same bore hole.

For very soft work in cuts and fills, or for quarry work when dimension stone is sought, black blasting powder is recommended. In grading work the blast hole may be bottomed out with dynamite before charging with granulated powder or with black blasting powder, but before it is charged care should be taken to see that the dynamite charge has not left any fire in the hole. In plastering or adobe work on bowlders and spawls, or in block holing, a strong dynamite should be used. Block holing is the more effective and economical method for use with bowlders.

If the straight nitroglycerin dynamites, as recommended above, are found to be too quick or too violent for use, and
Ammonia dyna- the results obtained are not as desired under the given
mites.   circumstances, ammonia dynamites, which give a more heaving and rending action, are recommended. They are made in several grades and are rated as of a certain percentage of strength, but this rating is not always made in a scientific way. The following composition is an example of that which is generally offered in this country as a 40 per cent strength ammonia dynamite:

Composition of 40 per cent strength ammonia dynamite.

	Per cent.
Nitroglycerin	22
Ammonium nitrate	20
Dope	58

This composition does not contain so large a percentage of nitroglycerin as the straight 40 per cent dynamite (see p. 19), and as tested at the Pittsburg testing station it is not found to produce the same results as the latter. Nevertheless the ammonia dynamites are often found to be more economical and more efficient for certain classes of work than the straight dynamites of the same commercial rating. The ammonia dynamites are less readily set off and are
Caution in use of safer to handle, transport, and store than the straight
ammonia dynamites. dynamites are, but they all require stronger detonators than the straight dynamites to insure a complete and rapid detonation. They have the disadvantage, compared with the straight dynamites, of taking up moisture very readily, and great care should be used in storing them or in using them in wet holes.

For use in very wet blasting and in places where there is poor
ventilation the gelatin dynamites are recommended.
Gelatin dynamites. Water has but little effect on them, and on complete explosion they yield only a small quantity of fumes and bad gases.

Like ammonia dynamites, gelatin dynamites are less sensitive than straight nitroglycerin dynamites, and they therefore require stronger detonators to cause their complete explosion. They become less sensitive during long storage, and they have been known after long storage in tropical countries to become so insensitive that they could not be detonated by means of the devices ordinarily used in firing them. Gelatin dynamite is likely to decompose during storage in very hot places.

Like the ammonia dynamites, the gelatin dynamites are sold in several grades and are given a somewhat unscientific rating in commerce. The grade known as 40 per cent strength gelatin dynamite, as generally offered in this country, has the following composition:

Composition of 40 per cent strength gelatin dynamite.

	Per cent.
Nitroglycerin	32
Soluble nitrocellulose	1
Dope	67

As tested at the Pittsburg testing station, gelatin dynamites have not been found to be equivalent in every respect to straight nitroglycerin dynamites of the same commercial rating, and as regards economy they should seldom be used as equivalent; but they are superior for some uses, as mentioned above.

SAFE SHIPMENT AND STORAGE OF EXPLOSIVES.

By B. W. Dunn.

Responsibility to public. A responsibility to the public rests upon both manufacturers and common carriers to secure the safe delivery at destination of explosives, and it is the duty of the owners of explosives to store them safely.

Federal law and Interstate Commerce Commission regulations. Under authority granted by Congress the Interstate Commerce Commission has made regulations, binding upon shippers and common carriers, for the transportation of explosives in interstate commerce, and the penalty of a possible fine of $2,000 and 18 months' imprisonment is prescribed by law for a violation of any of these regulations.

The shipper must know and certify on his shipping order that the explosive offered by him is in a proper condition for safe transportation and that it is packed and marked as required by the regulations. To perform this duty the shipper should be thoroughly familiar with all requirements pertaining to his shipment. A copy of the regulations can be obtained by application to the railway agent, whose duty it is to furnish them to shippers.

The following paragraphs in these regulations are of special interest to the shippers of explosives for use in mines: *General Rule A.*—Paragraphs 1501, 1502, 1503, 1509, 1510, 1531, 1533, 1541 to 1556, 1558 to 1560, 1611 to 1614, 1648, 1661, 1665, 1666, 1668, 1674 to 1683.

Explosives in baggage or household goods. Miners and other persons are sometimes tempted to pack explosives for shipment with their baggage on passenger cars, or with their household goods for shipment by freight. To do this is a criminal act that endangers the lives of the innocent and unsuspecting persons who have to handle these packages, and that subjects the guilty shipper, when detected, to arrest and prosecution. The Federal law (section 236) prescribes an imprisonment of 10 years for anyone convicted of this crime when death or bodily injury results from the illegal transportation of explosives. When no injury results the maximum penalty is 18 months' imprisonment and a fine of $2,000.

Magazine buildings. There is no standard type of storage magazine in use in this country, and the laws and regulations in foreign countries governing the construction of magazines differ materially. In Austria, for example, magazines are required to be of light construction, whereas in England they must have walls at least 18 inches thick.
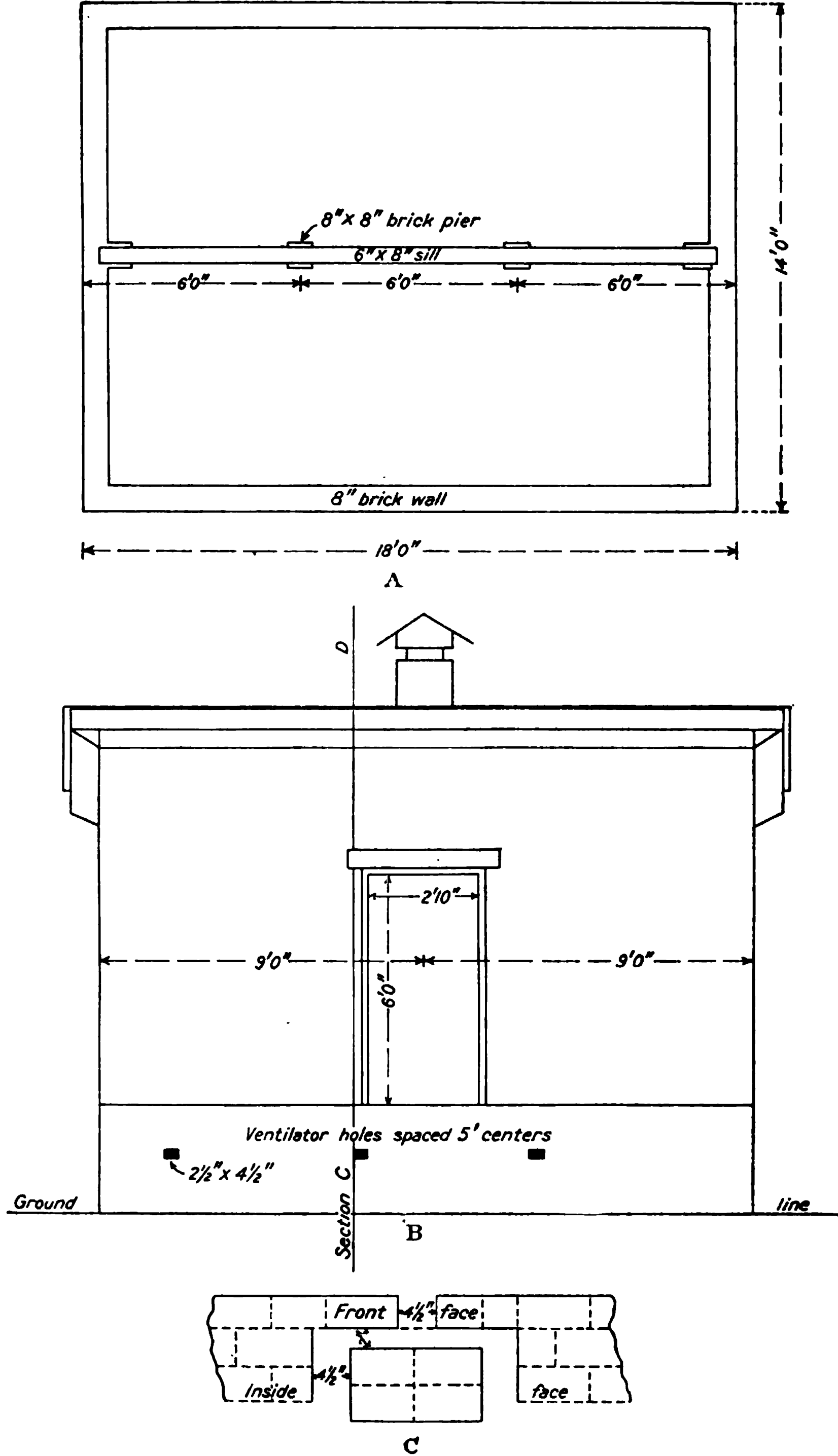
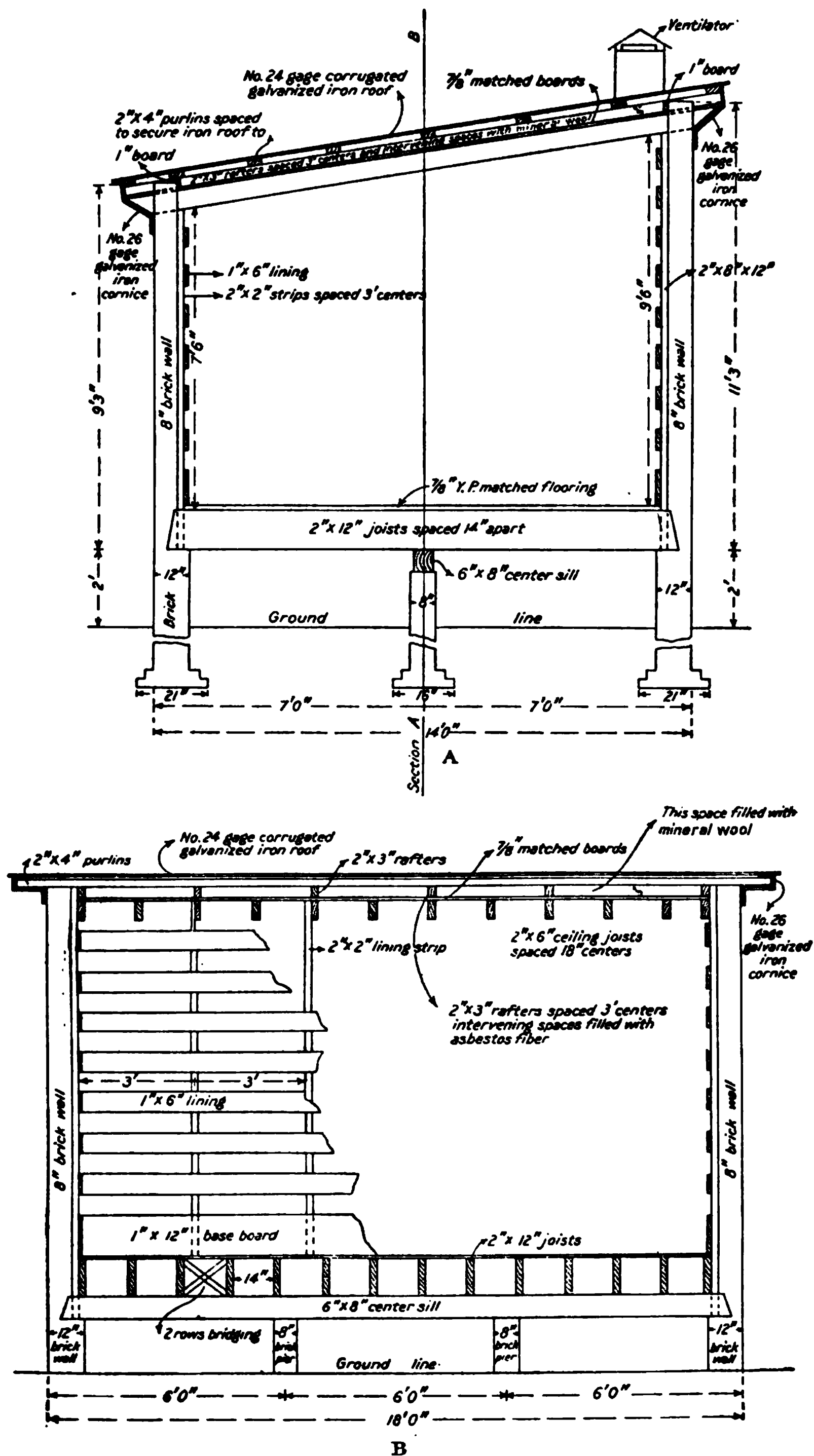FIGURE 11. Foundation plan (A), front elevation (B), and plan of ventilator hole (C) of brick magazine.

FIGURE 12.—Sections of magazine: A, section at line CD in fig. 11, B; B, section at line AB in fig. 12, A.

Explosives should be protected as far as practicable during storage against heat, moisture, fire, lightning, projectiles, and theft. The buildings should therefore be weatherproof, covered by fireproof and bullet-proof material, well ventilated, in secluded locations, and not exposed to fire risk from grass or underbrush. Lightning protectors are best placed on a line of supports encircling the building and 20 to 30 feet distant from it. Figures 11 and 12 show plans of an approved type of magazine.

In June, 1909, the chief inspector of the bureau of explosives of the American Railway Association brought to the attention of the man-

Isolation of maga-
zines.

ufacturers of explosives in the United States the dangers that attend the location of storage magazines too near railway property and invited a conference to discuss the steps that should be taken to remove these dangers.

A committee was appointed by the manufacturers to make an exhaustive study of all the data that could be collected the world over to show the damage that had resulted from explosions. As had been anticipated, a great deal of difficulty was experienced in getting reliable information in regard to this damage. The committee finally succeeded, however, in collecting more or less reliable information relating to over 130 explosions. From the data curves were platted on a large scale to show for the quantity of explosives involved the maximum distances at which structural damage to buildings had resulted from the explosions. The term structural damage covers injury to foundations, supporting walls (exterior or interior), or to roof or floor members. It does not include the breaking of glass or the shaking down of plaster.

From experience gained principally at manufacturing plants, it was concluded that an effective artificial barricade surrounding a magazine, or the intervention of a natural obstacle screening the property to be protected, would result in reducing the maximum distance observed in the case of unprotected magazines by 50 per cent. In studying the data collected, therefore, the curves were platted on the assumption that the magazine was thus barricaded or protected. With the exception of two or three instances, concerning which there was reasonable doubt of the reliability of the data collected, the curves were drawn to pass outside of all the platted points showing structural damage. From these curves the following table was prepared to show the distances that, according to the quantity of explosives involved, should separate storage magazines from inhabited dwellings and railways. For any such magazine not protected by an efficient barricade, or by natural protection, the distance should be doubled.

Minimum distances between barricaded magazines and railways or inhabited dwellings.

Quantity of explosives stored (pounds).	Proposed American distances (feet).		Quantity of explosives stored (pounds).	Proposed American distances (feet).	
	Inhabited buildings.	Public railway.		Inhabited buildings.	Public railway.
50	120	70	10,000	890	535
100	180	110	20,000	1,055	635
200	260	155	30,000	1,205	725
300	320	190	40,000	1,340	805
400	360	215	50,000	1,460	875
500	400	240	60,000	1,565	940
600	430	260	70,000	1,655	995
700	460	275	80,000	1,730	1,040
800	490	295	90,000	1,790	1,075
900	510	305	100,000	1,835	1,100
1,000	530	320	200,000	2,095	1,255
1,500	600	360	300,000	2,335	1,400
2,000	650	390	400,000	2,555	1,535
3,000	710	425	500,000	2,755	1,655
4,000	750	450	600,000	2,935	1,760
5,000	780	470	700,000	3,095	1,855
6,000	805	485	800,000.	3,235	1,940
7,000	830	500	900,000	3,355	2,015
8,000	850	510	1,000,000	3,455	2,075
9,000	870	520			

It should be understood that the proposed distances given in the above table have not yet been sanctioned by law. Whenever it becomes necessary, however, for a court to decide what would be a reasonable distance in a locality where such a distance is not specified by law, common practice would require resort to the testimony of experts. The above table represents the combined judgment of the best experts available, after an honest and prolonged study of all available data. It is probable, therefore, that the table will be accepted as a guide and that any person maintaining a storage magazine at distances less than those prescribed by it will be subject to successful prosecution before the courts for the maintenance of a public nuisance.

It will be advisable, therefore, for all interested parties to see at the earliest possible moment that their magazines are located in accordance with the above table. It is understood, of course, that, in any locality where the law on this subject is now specific, the law must be the guide.

Magazines should be kept clean and in thorough repair. Grounds around them should be kept clear of leaves, grass,

Care of magazines.

or other materials that might feed a fire. These words should be conspicuously posted on them: "Explosives—dangerous. No shooting allowed." The floors must be swept regularly and kept clean. The sweepings should be thrown in water or taken to a safe distance and destroyed.

In case floors become stained with nitroglycerin, cover the stains with dry sawdust, sweep up, and remove the sawdust. Then scrub the stains thoroughly with a hard brush and a solution of one-half pound of sulphide of sodium or sulphide of potassium in one-half gallon of wood alcohol.

Do not allow in the magazine any tools other than a wooden mallet and wooden wedge, or a phosphor-bronze chisel, and a screw driver to be used only for removing screws.

Do not open dynamite boxes with a nail puller or powder cans with pickaxes.

Remove all explosives from a magazine before repairing it.

Do not store detonators with explosives.

Do not open packages of explosives in a magazine.

Issue first the oldest explosives on hand.

Do not store dynamite boxes on end, as this increases the danger of nitroglycerin leaking from the cartridges.

Persons receiving packages of explosives sent by rail should examine them carefully to discover ruptures or other serious damage received during transit. Any information regarding such matters will be welcomed by the chief inspector, Bureau for the Safe Transportation of Explosives, 24 Park Place, New York City.

APPENDIX.

CONDITIONS UNDER WHICH EXPLOSIVES ARE TESTED.

The conditions under which the Bureau of Mines tests explosives to determine whether they shall be placed on its list of permissible explosives are as follows:

1. The manufacturer is to deliver to the BUREAU OF MINES, FORTIETH AND BUTLER STREETS, PITTSBURG, PA., *three weeks* prior to the date set for tests, 100 pounds of each explosive that he desires to have tested. He is to be responsible for the care, handling, and delivery of this material to the testing station and he is to have a representative present during the tests. In order to avoid duplication of work, it is requested that the *smallest size of cartridge* that the manufacturer intends to place on the market be sent for these tests.

2. No one is to be present at or participate in these tests except the necessary Government officers at the experiment station, their assistants, and the representative of the manufacturer of the explosives to be tested.

3. The tests will be made in the order of the receipt of the applications for them, provided the necessary quantity of the explosive is delivered at the testing station by the date set, of which date due notice will be given by the Bureau of Mines.

4. A list of the explosives which pass certain requirements satisfactorily will be furnished to State mine inspectors and will be made public in such other manner as may be considered desirable.

5. The details of results of tests are to be considered confidential by the manufacturer and are not to be made public prior to official publication by the Bureau of Mines.

6. From time to time field samples of permissible explosives will be collected, and tests will be made of these explosives as they are supplied for use in coal mines in the various States.

TEST REQUIREMENTS FOR EXPLOSIVES.

The tests will be made by the engineers of the United States mining experiment station at Pittsburg, Pa., in gas and dust gallery No. 1. The charge of explosives to be fired in tests 1, 2, and 3 shall be equal in deflective power, as determined by the ballistic pendulum, to one-half pound (227 grams) of 40 per cent nitroglycerin dynamite in its original wrapper, of the following formula:

	Per cent.
Nitroglycerin	40
Nitrate of soda (sodium nitrate)	44
Wood pulp	15
Carbonate of lime (calcium carbonate)	1
	100

Each charge shall be fired with an electric detonator (exploder or cap) strong enough to completely detonate or explode the charge, as recommended by the manufacturer. The explosive must be in such condition that the chemical and physical tests do not show any unfavorable results.

In order that the dust used in tests 2, 3, and 4 may be of the same quality, it is always taken from the same mine, ground to the same fineness, and used while still fresh.

The following are the tests to which are subjected the explosives that the Bureau of Mines is asked to place in the list of permissible explosives:

Test 1. Ten shots each with the charge as described above, in its original wrapper, shall be fired, each tamped with 1 pound[a] of clay stemming, at a gallery temperature of 77° F., into a mixture of gas and air containing 8 per cent of gas (methane and ethane). An explosive is considered to have passed the test if no one of the 10 successive shots ignites this mixture.

Test 2. Ten shots each with the charge as described above, in its original wrapper, shall be fired, each tamped with 1 pound[a] of clay stemming, at a gallery temperature of 77° F., into a mixture of gas and air containing 4 per cent of gas (methane and ethane) and 20 pounds of bituminous coal dust, 18 pounds of which is to be placed on shelves along the sides of the first 20 feet of the gallery, and 2 pounds to be so placed that it will be stirred up by an air current in such manner that all or part of it will be suspended in the first division of the gallery. An explosive is considered to have passed the test if no one of the 10 successive shots ignites this mixture.

Test 3. Ten shots each with the charge as described above, in its original wrapper, shall be fired, each tamped with 1 pound[a] of clay stemming, at a gallery temperature of 77° F., into 40 pounds of bituminous coal dust, 20 pounds of which is to be distributed uniformly on a steel trestle placed in front of the cannon and 20 pounds placed on side shelves in sections 4, 5, and 6. An explosive is considered to have passed the test if no one of the 10 successive shots ignites this mixture.

Test 4. A limit charge will be determined within 50 grams by firing charges in their original wrappers, without stemming, at a gallery temperature of 77° F., into a mixture of gas and air containing 4 per cent of gas (methane and ethane) and 20 pounds of bituminous coal dust, to be arranged in the same manner as in test 2. This limit-charge test is to be repeated five times under the same conditions before being established.

The tests now prescribed as those a permissible explosive must have passed are those given above. But even the explosives that have passed those tests and are published as permissible explosives are to be considered as permissible explosives only when used under the following conditions:

1. That the explosive is in all respects similar to the sample submitted by the manufacturer for test.

2. That No. 6 detonators—preferably No. 6 electric detonators (double strength)—are used of not less strength than 1 gram charge, consisting by weight of 90 parts of mercury fulminate and 10 parts of potassium chlorate (or their equivalents), except for the explosives "Bental coal powder No. 2," "Detonite special," "Hecla No. 2," "Kanite A," "Masurite M. L. F.," "Titanite No. 7–P," and "Titanite No. 8–P," for which the detonator shall be of not less strength than the No. 7·(1½ grams charge of the same mixture).

3. That the explosive, if frozen, shall be thoroughly thawed in a safe and suitable manner before use.

4. That the quantity used for a shot does not exceed 1½ pounds (680 grams), properly tamped.

It must not be supposed that an explosive that has once passed the above-mentioned tests and has been published in lists of permissible explosives is thereafter to be considered a permissible explosive, regardless of its condition or the way in which it is used. Thus, for example, an explosive named in the permissible list, if kept in a moist place until it undergoes a change in character, is no longer to be considered a permissible explosive. If used in a frozen or half-frozen condition, it is not when so used a permissible explosive. If used in excess of the quantity specified (1½ pounds), it is not when so used a permissible explosive. And when the other conditions have been met, it is not a permissible explosive if fired with a detonator of less than the prescribed strength.

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[a] Two pounds of clay stemming are used with slow-burning explosives.

Moreover, even when all the prescribed conditions have been met, no permissible explosive should necessarily be considered as permanently being a permissible explosive, but any permissible explosive when used under the prescribed conditions may properly continue to be considered a permissible explosive until notice of its withdrawal or removal from the list has been officially published, or until its name is omitted from a later list published by the Bureau of Mines.

Furthermore, the manufacturers of a permissible explosive may withdraw it at any time when introducing a new explosive of superior qualities. And after further experiments and conferences, the Bureau of Mines may find it advisable to adopt additional and more severe tests to which all permissible explosives may be subjected, in the hope that the lives of miners may be safeguarded better through the use of only those explosives that may pass the more severe tests.

PUBLICATIONS ON MINE ACCIDENTS AND EXPLOSIVES.

The following publications, except those to which a price is attached, can be had free by applying to the Director, Bureau of Mines, Washington, D. C. The priced publications can be had by sending the price, in cash, to the Superintendent of Documents, Government Printing Office, Washington, D. C.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

Bulletin 333. Coal-mine accidents; their causes and prevention; a preliminary statistical report, by Clarence Hall and W. O. Snelling, with introduction by J. A. Holmes. 1907. 21 pp. 5 cents.

Bulletin 369. The prevention of mine explosions. Report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 1908. 11 pp. 5 cents.

Bulletin 383. Notes on explosive mine gases and dusts, with special reference to the explosions in the Monongah, Darr, and Naomi coal mines, by R. T. Chamberlin. 1909. 67 pp.

Bulletin 425. The explosibility of coal dust, by George S. Rice, with chapters by J. C. Frazer, Alex Larsen, Frank Haas, and Carl Scholz. 1910. 186 pp., 14 pls.

PUBLICATIONS OF THE BUREAU OF MINES.

Bulletin 15. Tests of explosives used in coal mines, by Clarence Hall, W. O. Snelling, and S. P. Howell, with a chapter on the natural gas used at Pittsburg, by G. A. Burrell, and a preface by C. E. Munroe. (In press.)

Miners' Circular 2. Permissible explosives tested prior to January 1, 1911, and precautions to be observed in their use, by Clarence Hall. 1911. 12 pp.

Miners' Circular 3. Coal-dust explosions, by George S. Rice. 1911. 22 pp.

Miners' Circular 4. The use and care of mine-rescue breathing appratus, by J. W. Paul. 1911. 24 pp.

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